A SUPPLEMENT

To Mr. FERGUSON's Book of

LECTURES

ON

MECHANICS, HYDROSTATICS, PNEUMATICS, AND OPTICS.

WITH

The USE of the GLOBES,

AND

The ART of DIALLING.

CONTAINING

Thirteen COPPER-PLATES, with Descriptions, of the Machinery which he has added to his Apparatus, since *that* Book was printed.

By JAMES FERGUSON, *F. R. S.*

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A

SUPPLEMENT

TO

Mr. FERGUSON's Book of LECTURES.

MECHANICS.

The Description of a new and safe Crane, which has four different Powers, adapted to different Weights.

THE common crane consists only of a large wheel and axle; and the rope, by which goods are drawn up from ships, or let down from the quay to them, winds or coils round by the axle, as the axle is turned by men walking in the wheel. But, as these engines have nothing to stop the weight from running down, if any of the men happen to trip or fall in the wheel, the weight descends, and turns the wheel rapidly backward, and tosses the men violently about within it; which has produced melancholy instances, not only of limbs broke, but even of lives lost, by this ill-judged construction of cranes. And besides, they have but one power for all sorts of weights; so that they generally spend as much time in raising a small weight as in raising a great one.

 These

Theſe imperfections and dangers induced me to think of a method of remedying them. And for that purpoſe, I contrived a crane with a proper ſtop to prevent the danger, and with different powers ſuited to different weights; ſo that there might be as little loſs of time as poſſible: and alſo, that when heavy goods are let down into ſhips, the deſcent may be regular and deliberate.

This crane has four different powers: and, I believe, it might be built in a room eight feet in width: the gib being on the outſide of the room.

Three trundles, with different numbers of ſtaves, are applied to the cogs of a horizontal wheel with an upright axle; and the rope, that draws up the weight, coils round the axle. The wheel has 96 cogs, the largeſt trundle 24 ſtaves, the next largeſt has 12, and the ſmalleſt has 6. So that, the largeſt trundle makes 4 revolutions for one revolution of the wheel; the next makes 8, and the ſmalleſt makes 16. A winch is occaſionally put upon the axis of either of theſe trundles, for turning it; the trundle being then uſed that gives a power beſt ſuited to the weight: and the handle of the winch deſcribes a circle in every revolution equal to twice the circumference of the axle of the wheel. So that, the length of the winch doubles the power gained by each trundle.

As the power gained by any machine, or engine whatever, is in direct proportion as the velocity of the power is to the velocity of the weight; the powers of this crane are eaſily eſtimated, and they are as follows.

If the winch be put upon the axle of the largeſt trundle, and turned four times round, the wheel and axle will be turned once round: and the circle deſcribed by the power that turns the winch, being, in each revolution, double the circumference of the axle, when the thickneſs of the rope is added thereto; the power goes through eight times as

as much space as the weight rises through: and therefore (making some allowance for friction) a man will raise eight times as much weight by the crane as he would by his natural strength without it: the power, in this case, being as eight to one.

If the winch be put upon the axis of the next trundle, the power will be as sixteen to one, because it moves 16 times as fast as the weight moves.

If the winch be put upon the axis of the smallest trundle, and turned round; the power will be as 32 to one.

But, if the weight should be too great, even for this power to raise, the power may be doubled by drawing up the weight by one of the parts of a double rope, going under a pulley in the moveable block which is hooked to the weight below the arm of the gib; and then the power will be as 64 to one. That is, a man could then raise 64 times as much weight by the crane as he could raise by his natural strength without it; because, for every inch that the weight rises, the working power will move through 64 inches.

By hanging a block with two pullies to the arm of the gib, and having two pullies in the moveable block that rises with the weight, the rope being doubled over and under these pullies, the power of the crane will be as 64 to one. And so, by increasing the number of pullies, the power may be increased as much as you please: always remembering, that the larger the pullies are, the less is their friction.

Whilst the weight is drawing up, the ratch-teeth of a wheel slip round below a catch or click that falls successively into them, and so hinders the crane from turning backward, and detains the weight in any part of its ascent, if the man who works at the winch should accidentally happen to quit his hold, or choose to rest himself before the weight be quite drawn up.

In order to let down a weight, a man pulls down one end of a lever of the ſecond kind, which lifts the catch out of the ratchet-wheel, and gives the weight liberty to deſcend. But, if the deſcent be too quick, he pulls the lever a little farther down, ſo as to make it rub againſt the outer edge of a round wheel; by which means he lets down the weight as ſlowly as he pleaſes: and, by pulling a little harder, he may ſtop the weight, if needful, in any part of its deſcent. If he accidentally quits hold of the lever, the catch immediately falls, and ſtops both the weight and the whole machine.

This crane is repreſented in PLATE I. where *A* is the great wheel, and *B* its axle on which the rope *C* winds. This rope goes over a pulley *D* in the end of the arm of the gib *E*, and draws up the weight *F*, as the winch *G* is turned round. *H* is the largeſt trundle, *I* the next, and *K* is the axis of the ſmalleſt trundle, which is ſuppoſed to be hid from view by the upright ſupporter *L*. A trundle *M* is turned by the great wheel, and on the axis of this trundle is fixed the ratchet-wheel *N*, into the teeth of which the catch *O* falls. *P* is the lever, from which goes a rope *QQ*, over a pulley *R* to the catch; one end of the rope being fixed to the lever, and the other end to the catch. *S* is an elaſtic bar of wood, one end of which is ſcrewed to the floor: and, from the other end goes a rope (out of ſight in the figure) to the further end of the lever, beyond the pin or axis on which it turns in the upright ſupporter *T*. The uſe of this bar is to keep up the lever from rubbing againſt the edge of the wheel *U*, and to let the catch keep in the teeth of the ratchet-wheel: But, a weight hung to the farther end of the lever would do full as well as the elaſtic bar and rope.

When the lever is pulled down, it lifts the catch out of the ratchet-wheel, by means of the rope *QQ*, and gives the weight *F* liberty to deſcend: but if the lever *P* be pulled a little farther down than what is ſufficient to lift the catch *O* out of the ratchet-wheel *N*, it will rub againſt the edge of the wheel *U*, and thereby hinder the too

quick

quick descent of the weight; and will quite stop the weight if pulled hard. And if the man, who pulls the lever, should happen inadvertently to let it go; the elastic bar will suddenly pull it up, and the catch will fall down and stop the machine.

WW are two upright rollers, above the axis or upper gudgeon of the gib *E*: their use is to let the rope *C* bend upon them, as the gib is turned to either side, in order to bring the weight over the place where it is intended to be let down.

N. B. The rollers ought to be so placed, that if the rope *C* be stretched close by their outmost sides, the half thickness of the rope may be perpendicularly over the center of the upper gudgeon of the gib. For then, and in no other position of the rollers, the length of the rope between the pulley in the gib and the axle of the great wheel will be always the same, in all positions of the gib: and the gib will remain in any position to which it is turned.

When either of the trundles is not turned by the winch in working the crane, it may be drawn off from the wheel, after the pin near the axis of the trundle is drawn out, and the thick piece of wood is raised a little behind the outward supporter of the axis of the trundle. But this is not material: for, as the trundle has no friction on its axis but what is occasioned by its weight, it will be turned by the wheel without any sensible resistance in working the crane.

A Pyrometer, that makes the Expansion of Metals by Heat visible to the five and forty thousandth Part of an Inch.

The upper surface of this machine is represented by *Fig.* 1. of Plate II. Its frame *ABCD* is made of mahogany wood, on which is a circle divided into 360 equal parts; and within that circle is an-

 other,

other, divided into 8 equal parts. If the short bar *E* be pushed one inch forward (or toward the center of the circle) the index *e* will be turned 125 times round the circle of 360 parts or degrees. As 125 times 360 is 45,000, 'tis evident, that if the bar *E* be moved only the 45,000dth part of an inch, the index will move one degree of the circle. But, as in my pyrometer, the circle is 9 inches in diameter, the motion of the index is visible to half a degree, which answers to the ninety thousandth part of an inch in the motion or pushing of the short bar *E*.

One end of a long bar of metal *F* is laid into a hollow place in a piece of iron *G*, which is fixed to the frame of the machine; and the other end of this bar is laid against the end of the short bar *E*, over the supporting cross bar *HI*: and, as the end *f* of the long bar is placed close against the end of the short bar, 'tis plain, that if *F* expands, it will push *E* forward, and turn the index *e*.

The machine stands on four short pillars, high enough from a table, to let a spirit-lamp be put on the table under the bar *F*; and, when that is done, the heat of the flame of the lamp expands the bar, and turns the index.

There are bars of different metals, as silver, brass, and iron; all of the same length as the bar *F*, for trying experiments on the different expansion of different Metals, by equal degrees of heat applied to them for equal lengths of time; which may be measured by a pendulum, that swings seconds. Thus,

Put on the brass bar *F*, and set the index to the 360th degree: then put the lighted lamp under the bar, and count the number of seconds in which the index goes round the plate, from 360 to 360 again; and then blow out the lamp, and take away the bar.

This done, put on an iron-bar *F* where the brass one was before, and then set the index to the 360th degree again. Light the lamp, and

and put it under the iron-bar, and let it remain just as many seconds as it did under the brass one; and then blow it out, and you will see how many degrees the index has moved in the circle: and by that means you will know in what proportion the expansion of iron is to the expansion of brass; which I find to be as 210 is to 360, or as 7 is to 12.——By this method, the relative expansion of different metals may be found.

The bars ought to be exactly of equal size; and to have them so, they should be drawn, like wire through a hole.

When the lamp is blown out, you will see the index turn backward; which shews that the metal contracts as it cools.

The inside of this pyrometer is constructed as follows.

In *Fig.* 2. *Aa* is the short bar, which moves between rollers; and, on the side *a* it has 15 teeth in an inch, which take into the leaves of a pinion *B* (12 in number) on whose axis is the wheel *C* of 100 teeth, which take into the 10 leaves of the pinion *D*, on whose axis is the wheel *E* of 100 teeth, which take into the 10 leaves of the pinion *F*, on the top of whose axis is the index above-mentioned.

Now, as the wheels *C* and *E* have 100 teeth each, and the pinions *D* and *F* have ten leaves each; 'tis plain, that if the wheel *C* turns once round, the pinion *F* and the index on its axis will turn 100 times round. But, as the first pinion *B* has only 12 leaves, and the bar *Aa* that turns it has 15 teeth in an inch, which is 12 and a fourth part more; one inch motion of the bar will cause the last pinion *F* to turn an hundred times round, and a fourth part of an hundred over and above, which is 25. So that, if *Aa* be pushed one inch, *F* will be turned 125 times round.

A ſilk thread *b* is tied to the axis of the pinion *D*, and wound ſeveral times round it; and the other end of the thread is tied to a piece of ſlender watch-ſpring *G* which is fix'd into the ſtud *H*. So that, as the bar *f* expands, and puſhes the bar *Aa* forward, the thread winds round the axle, and draws out the ſpring, and as the bar contracts, the ſpring pulls back the thread, and turns the work the contrary way, which puſhes back the ſhort bar *Aa* againſt the long bar *f*.—This ſpring always keeps the teeth of the wheels in contact with the leaves of the pinions, and ſo prevents any ſhake in the teeth.

In *Fig*. 1. the eight diviſions of the inner circle are ſo many thouſandth parts of an inch in the expanſion or contraction of the bars; which is juſt one thouſandth part of an inch for each diviſion moved over by the index.

A Water-Mill, invented by Dr. Barker, *that has neither Wheel nor Trundle.*

This machine is repreſented by *Fig*. 1. of Plate III. in which, *A* is a pipe or channel that brings water to the upright tube *B*. The water runs down the tube, and thence into the horizontal trunk *C*, and runs out through holes at *d* and *e* near the ends of the trunk on the contrary ſides thereof.

The upright ſpindle D is fixt in the bottom of the trunk, and ſcrewed to it below by the nut *g*; and is fixt into the trunk by two croſs bars at *f*: ſo that, if the tube *B* and trunk *C* be turned round, the ſpindle *D* will be turned alſo.

The top of the ſpindle goes ſquare into the rynd of the upper millſtone *H*, as in common mills; and, as the trunk, tube, and ſpindle turn

turn round, the mill-ſtone is turned round thereby. The lower, or quieſcent mill-ſtone is repreſented by *I*; and *K* is the floor on which it reſts, and wherein is the hole *L* for letting the meal run through, and fall down into a trough which may be about *M*. The hoop or caſe that goes round the mill-ſtone reſts on the floor *K*, and ſupports the hopper, in the common way. The lower end of the ſpindle turns in a hole in the bridge-tree *G F*, which ſupports the mill-ſtone, tube, ſpindle, and trunk. This tree is moveable on a pin at *b*, and its other end is ſupported by an iron-rod *N* fixt into it, the top of the rod going through the fixt bracket *O*, and having a ſcrew-nut *o* upon it, above the bracket. By turning this nut forward or backward, the mill-ſtone is raiſed or lowered at pleaſure.

Whilſt the tube *B* is kept full of water from the pipe *A*, and the water continues to run out from the ends of the trunk; the upper mill-ſtone *H*, together with the trunk, tube, and ſpindle, turns round. But, if the holes in the trunk were ſtopt, no motion would enſue; even though the tube and trunk were full of water. For,

If there were no hole in the trunk, the preſſure of the water would be equal againſt all parts of its ſides within. But, when the water has free egreſs through the holes, its preſſure there is entirely removed: and the preſſure againſt the parts of the ſides which are oppoſite to the holes, turns the machine.

HYDROSTATICS.

A Machine for demonstrating that, on equal Bottoms, the Pressure of Fluids is in Proportion to their perpendicular Heights, without any regard to their Quantities.

THIS is termed *The Hydrostatical Paradox*; and the machine for shewing it is represented in *Fig.* 2. of Plate III. In which, *A* is a box that holds about a pound of water, *a b c d e* a glass-tube fixt in the top of the box, having a small wire within it; one end of the wire being hooked to the end *F* of the beam of a balance, and the other end of the wire fixt to a moveable bottom, on which the water lies, within the box; the bottom and wire being of equal weight with an empty scale (out of sight in the figure) hanging at the other end of the balance. If this scale be pulled down, the bottom will be drawn up within the box, and that motion will cause the water to rise in the glass-tube.

Put one pound weight into the scale, which will move the bottom a little, and cause the water to appear just in the lower end of the tube at *a*; which shews that the water presses with the force of one pound on the bottom: put another pound into the scale, and the water will rise from *a* to *b* in the tube, just twice as high above the bottom as it was when at *a*; and then, as its pressure on the bottom supports two pound weight in the scale, 'tis plain that the pressure on the bottom is then equal to two pounds. Put a third pound weight in the scale, and the water will be raised from *b* to *c* in the tube, three times as high above the bottom as when it began to appear in the tube at *a*; which shews, that the same quantity of water that pressed,

pressed, but with the force of one pound on the bottom, when raised no higher than *a*, presses with the force of three pounds on the bottom when raised three times as high to *c* in the tube. Put a fourth pound weight into the scale, and it will cause the water to rise in the tube from *c* to *d*, four times as high as it was when it was all contained in the box, which shews that its pressure then upon the bottom is four times as great as when it lay all within the box. Put a fifth pound weight into the scale, and the water will rise in the tube from *d* to *e*, five time as high as it was above the bottom before it rose in the tube; which shews that its pressure on the bottom is then equal to five pounds, seeing that it supports so much weight in the scale. And so on, if the tube was still longer; for it would still require an additional pound put into the scale, to raise the water in the tube to an additional height equal to the space *de*; even if the bore of the tube was so small as only to let the wire move freely within it, and leave room for any water to get around the wire.

Hence we infer, that if a long narrow pipe or tube was fixed in the top of a cask full of liquor, and if as much liquor was poured into the tube as would fill it, even though it were so small as not to hold an ounce weight of liquor; the pressure arising from the liquor in the tube would be as great upon the bottom, and be in as much danger of bursting it out, as if the cask was continued up, in its full size, to the height of the tube, and filled with liquor.

In order to account for this surprising affair, we must consider that fluids press equally in all manner of directions; and, consequently that they press just as strongly upward as they do downward. For, if another tube, as *f* be put into a hole made in the top of the box, and the box be filled with water; and then, if water be poured in at the top of the tube *abcde*, it will rise in the tube *f* to the same height as it does in the other tube: and if you leave off pouring, when the water is at *c*, or any other place in the tube *abcde*, you will find

it juſt as high in the tube *f*: and if you pour in water to fill the firſt tube, the ſecond will be filled alſo.

Now it is evident that the water riſes in the tube *f*, from the downward preſſure of the water in the tube *abcde*, on the ſurface of the water, contiguous to the inſide of the top of the box; and as it will ſtand at equal heights in both tubes, the upward preſſure in the tube *f* is equal to the downward preſſure in the other tube. But, if the tube *f* were put in any other part of the top of the box, the riſing of the water in it would ſtill be the ſame: or, if the top was full of holes, and a tube put into each of them, the water would riſe as high in each tube as it was poured into the tube *abcde*; and then the moveable bottom would have the weight of the water in all the tubes to bear, beſides the weight of all the water in the box.

And ſeeing that the water is preſſed upward into each tube, 'tis evident that, if they be all taken away, excepting the tube *abcde*, and the holes in which they ſtood be ſtopt up; each part, thus ſtopt, will be preſſed as much upward as was equal to the weight of water in each tube. So that, the upward preſſure againſt the inſide of the top of the box, on every part equal in breadth to the width of the tube *abcde*, will be preſſed upward with a force equal to the whole weight of water in the tube. And conſequently, the whole upward preſſure againſt the top of the box, ariſing from the weight or downward preſſure of the water in the tube, will be equal to the weight of a column of water of the ſame height with that in the tube, and of the ſame thickneſs as the width of the inſide of the box: and this upward preſſure againſt the top will re-act downward againſt the bottom, and be as great thereon, as would be equal to the weight of a column of water as thick as the moveable bottom is broad, and as high as the water ſtands in the tube. And thus, the paradox is ſolved.

The

The moveable bottom has no friction against the inside of the box, nor can any water get between it and the box. The method of making it so, is as follows:

In *Fig.* 3. *ABCD* represents a section of the box, and *abcd* is the lid or top thereof, which goes on tight, like the lid of a common paper snuff-box. *E* is the moveable bottom, with a groove around its edge, and it is put into a bladder *fg*, which is tied close around it in the groove by a strong waxed thread; the bladder coming up like a purse within the box, and put over the top of it at *a* and *d* all round, and then the lid pressed on. So that, if water be poured in through the hole *ll* of the lid, it will lie upon the bottom *E*, and be contained in the space *fEgb* within the bladder; and the bottom may be raised by pulling the wire *i*, which is fixed to it at *E*: and by thus pulling the wire, the water will be lifted up in the tube *k*, and as the bottom does not touch against the inside of the box, it moves without friction.

Now, suppose the diameter of this round bottom to be three inches (in which case, the area thereof will be 9 circular inches) and the diameter of the bore of the tube to be a quarter of an inch; the whole area of the bottom will be 144 times as great as the area of the top of a pin that would fill the tube like a cork.

And hence it is plain, that if the moveable bottom be raised only the 144th part of an inch, the water will thereby be raised a whole inch in the tube; and consequently, that if the bottom be raised one inch, it would raise the water to the top of a tube 144 inches, or 12 feet, in height.

N. B. The box must be open below the moveable bottom, to let in the air. Otherwise, the pressure of the atmosphere would be so great upon the moveable bottom, if it be three inches in diameter, as

as to require 108 pounds in the ſcale, to balance that preſſure, before the bottom can begin to move.

A Machine, to be ſubſtituted in Place of the common Hydroſtatical Bellows.

In *Fig.* 1. of PLATE IV. *ABCD* is an oblong ſquare box, in one end of which is a round groove, as at *a*, from top to bottom, for receiving the upright glaſs tube *I*, which is bent to a right angle at the lower end (as at *i* in *Fig.* 2.) and to that part is tied the end of a large bladder *K*, (Fig. 2.) which lies in the bottom of the box. Over this bladder is laid the moveable board *L* (*Fig.* 1. and 2.) in which is fixt an upright wire *M*; and leaden weights, *NN*, to the amount of 16 pounds, with holes in their middle, are put upon the wire, over the board, and preſs upon it with all their force.

The croſs bar *p* is then put on, to ſecure the tube from falling, and keep it in an upright poſition: And then the piece *EFG* is to be put on, the part *G* ſliding tight into the dove-tail'd groove *H*, to keep the weights *NN* horizontal, and the wire *M* upright; there being a round hole *e* in the part *EF* for receiving the wire.

There are four upright pins in the four corners of the box within, each almoſt an inch long, for the board *L* to reſt upon; to keep it from preſſing the ſides of the bladder below it cloſe together at firſt.

The whole machine being thus put together, pour water into the tube at top; and the water will run down the tube into the bladder below the board: and after the bladder has been filled up to the board, continue pouring water into the tube, and the upward preſſure which it will excite in the bladder, will raiſe the board with all the weight

weight upon it, even though the bore of the tube should be so small, that less than an ounce of water would fill it.

This machine acts upon the same principle, as the one last described, concerning the *Hydrostatical paradox*. For, the upward pressure against every part of the board (which the bladder touches) equal in area to the area of the bore of the tube, will be pressed upward with a force equal to the weight of the water in the tube; and the sum of all these pressures, against so many areas of the board, will be sufficient to raise it with all the weights upon it.

In my opinion, nothing can exceed this simple machine, in making the upward pressure of fluids evident to sight.

The Cause of reciprocating Springs, and of ebbing and flowing Wells, explained.

In *Fig.* 1. of PLATE V. Let *abcd* be a hill, within which is a large cavern *AA* near the top, filled or fed by rains and melted snow on the top *a*, making their way through chinks and crannies into the said cavern, from which proceeds a small stream *ce* within the body of the hill, and issues out in a spring at *G* on the side of the hill, which will run constantly whilst the cavern is fed with water.

From the same cavern *AA*, let there be a small channel *D*, to carry water into the cavern *B*; and from that cavern, let there be a bended channel *EeF*, larger than *D*, joining with the former channel *cc*, as at *f* before it comes to the side of the hill: and let the joining at *f* be below the level of the bottom of both these caverns.

As the water rises in the cavern *B*, it will rise as high in the channel *EeF*; and when it rises to the top of that channel at *e*, it will run

down the part eFG, and make a ſwell in the ſpring G, which will continue till all the water is drawn off from the cavern B, by the natural ſyphon EeF, (which carries off the water faſter from B, than the channel D brings water to it) and then the ſwell will ſtop, and only the ſmall channel CC will carry water to the ſpring G, till the cavern B is filled to B again by the rill D; and then the water being at the top e of the channel EeF, that channel will act again as a ſyphon, and carry off all the water from B to the ſpring G, and ſo make a ſwelling flow of water at G as before.

To illuſtrate this by a machine (*Fig.* 2.) let A be a large wooden box, filled with water; and let a ſmall pipe CC (the upper end of which is fixed into the bottom of the box) carry water from the box to G, where it will run off conſtantly, like a ſmall ſpring. Let another ſmall pipe D carry water from the ſame box to the box or well B, from which let a ſyphon EeF proceed, and join with the pipe CC at f: the bore of the ſyphon being larger than the bore of the feeding pipe D. As the water from this pipe riſes in the well B, it will alſo riſe as high in the ſyphon EeF: and when the ſyphon is full to the top e, the water will run over the bend e, down the part eF, and go off at the mouth G; which will make a great ſtream at G: and that ſtream will continue, till the ſyphon has carried off all the water from the well B; the ſyphon carrying off the water faſter from B than the pipe D brings water to it: and then the ſwell at G will ceaſe, and only the water from the ſmall pipe CC will run off at G, till the pipe D fills the well B again; and then the ſyphon will run, and make a ſwell at G as before.

And thus, we have an artificial repreſentation of an ebbing and flowing well, and of a reciprocating ſpring, in a very natural and ſimple manner.

HYDRAU-

HYDRAULICS.

An Account of the Principles by which Mr. Blakey *proposes to raise Water from Mines, or from Rivers to supply Towns and Gentlemens Seats, by his new invented Fire-Engine, for which he has received* His MAJESTY'S *Patent.*

ALTHOUGH I am not at liberty to describe the whole of this simple engine, yet I have the patentee's leave to describe such a one as will shew the principles by which it acts.

In *Fig.* 4. of PLATE IV. let *A* be a large, strong, close vessel; immersed in water up to the cock *b*, and having a hole in the bottom, with a valve *a* upon it, opening upward within the vessel. A pipe *B C* rises from the bottom of this vessel, and has a cock *c* in it near the top, which is small there, for playing a very high jet *d*. *E* is the little boiler (not so big as a common tea-kettle) which is connected with the vessel *A* by the steam-pipe *F*; and *G* is a funnel, through which, a little water must be occasionally poured into the boiler, to yield a proper quantity of steam. And a small quantity of water will do for that purpose, because steam possesseth upwards of 14,000 times as much space or bulk as the water does from which it proceeds.

The vessel *A* being immersed in water up to the cock *b*, open that cock, and the water will rush in, through the bottom of the vessel at *a*, and fill it as high up as the water stands on its outside; and the water, coming into the vessel, will drive the air out of it (as high as the water rises within it) through the cock *b*. When the water has done rushing into the vessel, shut the cock *b*, and the valve *a* will

fall down, and hinder the water from being pushed out that way, by any force that presseth on its surface. All the part of the vessel above *b*, will be full of common air, when the water rises to *b*.

Shut the cock *c*, and open the cocks *d* and *e*; then pour as much water into the boiler *E* (through the funnel *G*) as will about half fill the boiler; and then shut the cock *d*, and leave the cock *e* open.

This done, make a fire under the boiler *E*, and the heat thereof will raise a steam from the water in the boiler; and the steam will make its way thence, through the pipe *F*, into the vessel *A*; and the steam will compress the air (above *b*) with a very great force upon the surface of the water in *A*.

When the top of the vessel *A* feels very hot by the steam under it, open the cock *c* in the pipe *C*; and the air being strongly compressed in *A*, between the steam and the water therein, will drive all the water out of the vessel *A*, up the pipe *BC*, from which it will fly up in a jet to a very great height.—— In my fountain, which is made in this manner after Mr. Blakey's, three tea-cup-fulls of water in the boiler will afford steam enough to play a jet 30 feet high.

When all the water is out of the vessel *A*, and the compressed air begins to follow the jet, open the cocks *b* and *d* to let the steam out of the boiler *E* and vessel *A*, and shut the cock *e* to prevent any more steam from getting into *A*; and the air will rush into the vessel *A* through the cock *b*, and the water through the valve *a*; and so the vessel will be filled up with water to the cock *b* as before. Then shut the cock *b* and the cocks *c* and *d*, and open the cock *e*; and then, the next steam that rises in the boiler will make its way into the vessel *A* again; and the operation will go on, as above.

When all the water in the boiler *E* is evaporated, and gone off into steam, pour a little more into the boiler, through the funnel *G*.

In

In order to make this engine raiſe water to any gentleman's houſe; if the houſe be on the bank of a river, the pipe *BC* may be continued up to the intended height, in the direction *HI*. Or, if the houſe be on the ſide or top of a hill, at a diſtance from the river, the pipe, through which the water is forced up, may be laid along on the hill, from the river or ſpring to the houſe.

The boiler may be fed by a ſmall pipe *K*, from the water that riſes in the main pipe *BCHI*: the pipe *K* being of a very ſmall bore, ſo as to fill the funnel *G* with water in the time that the boiler *E* will require a freſh ſupply. And then, by turning the cock *d*, the water will fall from the funnel into the boiler. The funnel ſhould hold as much water as will about half fill the boiler.

When either of theſe methods of raiſing water, perpendicularly or obliquely, is uſed; there will be no occaſion for having the cock *e* in the main pipe *BCHI*: for ſuch a cock is requiſite only, when the engine is uſed as a fountain.

A contrivance may be very eaſily made, from a lever to the cocks *b*, *d*, and *e*; ſo that, by pulling the lever, the cocks *b* and *d* may be opened when the cock *e* muſt be ſhut; and the cock *e* be opened when *b* and *d* muſt be ſhut.

The boiler *E* ſhould be incloſed in a brick wall, at a little diſtance from it, all around; to give liberty for the flames of the fire under the boiler to aſcend round about it. By which means, (the wall not covering the funnel *G*,) the force of the ſteam will be prodigiouſly increaſed by the heat round the boiler; and the funnel and water in it will be heated from the boiler; ſo that, the boiler will not be chilled by letting cold water into it; and the riſing of the ſteam will be ſo much the quicker.

Mr.

Mr. Blakey is the only person who ever thought of making use of air as an intermediate body between steam and water: by which means, the steam is always kept from touching the water, and consequently from being condensed by it. And, on this new principle, he has obtained a patent: so that no one (vary the engine how he will) can make use of air between steam and water, without infringing on the patent, and being subject to the penalties of the law.

This engine may be built for a trifling expence, in comparison of the common fire engine now in use: it will seldom need repairs, and will not consume half so much fuel. And as it has no pumps with pistons, it is clear of all their friction; and the effect is equal to the whole strength or compressive force of the steam: which the effect of the common fire engine never is on account of the great friction of the pistons in their pumps.

ARCHIMEDES's *Screw-Engine for raising Water.*

In *Fig.* 1. of PLATE VI. *ABCD* is a wheel, which is turned round, according to the order of the letters, by the fall of water *EF*, which need not be more than three feet. The axle *G* of the wheel is elevated so, as to make an angle of about 44 degrees with the horizon; and on the top of that axle is a wheel *H* which turns such another wheel *I* of the same number of teeth: the axle *K* of this last wheel being parallel to the axle *G* of the two former wheels.

The axle *G* is cut into a double threaded screw (as in Fig. 2.) exactly resembling the screw on the axis of the fly of a common jack, which must be (what is called) a right handed screw, like the wood-screws, if the first wheel turns in the direction *ABCD*; but must be a left handed screw, if the stream turns the wheel the contrary way. And, which ever way the screw on the axle *G* be

cut; the ſcrew on the axle *K* muſt be cut the contrary way; becauſe theſe axles turn in contrary directions.

The ſcrews being thus cut, they muſt be covered cloſe over with boards, like thoſe of a cylindrical caſk; and then they will be ſpiral tubes. Or, they may be made of tubes of ſtiff leather, and wrapt round the axles in ſhallow grooves cut therein; as in *Fig*. 3.

The lower end of the axle *G* turns conſtantly in the ſtream that turns the wheel, and the lower ends of the ſpiral tubes are open into the water. So that, as the wheel and axle are turned round, the water riſes in the ſpiral tubes, and runs out at *L*, through the holes *M, N*, as they come about below the axle. Theſe holes (of which there may be any number, as four or ſix) are in a broad cloſe ring on the top of the axle, into which ring, the water is delivered from the upper open ends of the ſcrew-tubes, and falls into the open box *N*.

The lower end of the axle *K* turns on a gudgeon, in the water in *N*; and the ſpiral tubes in that axle take up the water from *N*, and deliver it into ſuch another box under the top of *K*; on which there may be ſuch another wheel as *I*, to turn a third axle by ſuch a wheel upon it.——And in this manner, water may be raiſed to any given height, when there is a ſtream ſufficient for that purpoſe to act on the broad float boards of the firſt wheel.

A quadruple Pump-Mill for raiſing Water.

This engine is repreſented in PLATE VII. In which *ABCD* is a wheel, turned by water according to the order of the letters. On the horizonal axis are four ſmall wheels, toothed almoſt half round; and the parts of their edges on which there are no teeth are cut down ſo, as to be even with the bottoms of the teeth where they ſtand.

The

The teeth of these four wheels take alternately into the teeth of four racks, which hang by two chains over the pullies *Q* and *L*; and to the lower ends of these racks there are four iron rods fixed, which go down into the four forcing pumps, *S*, *R*, *M*, and *N*. And, as the wheels turn, the racks and pump-rods are alternately moved up and down.

Thus, suppose the wheel *G* has pulled down the rack *I*, and drawn up the rack *K* by the chain: as the last tooth of *G* just leaves the uppermost tooth of *I*, the first tooth of *H* is ready to take into the lowermost tooth of the rack *K* and pull it down as far as the teeth go; and then the rack *I* is pulled upward through the whole space of its teeth, and the wheel *G* is ready to take hold of it, and pull it down again, and so draw up the other. —— In the same manner, the wheels *E* and *F* work the racks *O* and *P*.

These four wheels are fixed on the axle of the great wheel in such a manner, with respect to the positions of their teeth; that, whilst they continue turning round, there is never one instant of time in which one or other of the pump-rods is not going down, and forcing the water. So that, in this engine, there is no occasion for having a general air-vessel to all the pumps, to procure a constant stream of water flowing from the upper end of the main pipe.

The pistons of these pumps are solid plungers, the same as described in the fifth Lecture of my book, to which this is a Supplement. *See* PLATE XI. *Fig.* 4. *of that book, with the description of the figure.*

From each of these pumps, near the lowest end, in the water, there goes off a pipe, with a valve on its farthest end from the pump; and these ends of the pipes all enter one close box, into which they deliver the water: and into this box, the lower end of the main conduct pipe is fixed. So that, as the water is forced or pushed into

the box, it is alſo puſhed up the main pipe to the height that it is intended to be raiſed.

There is an engine of this ſort, deſcribed in *Ramelli's* works: but I can truly ſay, that I never ſaw it till ſome time after I had made this model.

The ſaid model is not above twice as big as the figure of it, here deſcribed. I turn it by a winch fixed on the gudgeon of the axle behind the water wheel; and, when it was newly made, and the piſtons and valves in good order, I put tin pipes 15 feet high upon it, when they were joined together, to ſee what it could do. And I found, that in turning it moderately by the winch, it would raiſe a hogſhead of water in an hour, to the height of 15 feet.

DIALLING.

The univerſal Dialling Cylinder.

IN *Fig.* 1. of PLATE VIII. *ABCD* repreſents a cylindrical glaſs tube, cloſed at both ends with braſs plates, and having a wire or axis *EFG* fixt in the centers of the braſs plates at top and bottom. This tube is fixed to a horizontal board *H*, and its axis makes an angle with the board equal to the angle of the earth's axis with the horizon of any given place, for which the cylinder is to ſerve as a dial. And it muſt be ſet with its axis parallel to the axis of the world in that place; the end *E* pointing to the elevated pole. Or, it may be made to move upon a joint; and then it may be elevated for any particular latitude.

There are 24 ſtraight lines, drawn with a diamond, on the outſide of the glaſs, equidiſtant from each other, and all of them parallel to the axis. Theſe are the hour-lines; and the hours are ſet to them as

in the figure: the XII next *B* ſtands for midnight, and the oppoſite XII, next the board *H*, ſtands for mid-day or noon.

The axis being elevated to the latitude of the place, and the foot-board ſet truly level, with the black line along its middle in the plane of the meridian, and the end *N* toward the north; the axis *EFG* will ſerve as a ſtile or gnomon, and caſt a ſhadow on the hour of the day, among the parallel hour lines, when the ſun ſhines on the machine. For, as the ſun's apparent diurnal motion is equable in the heavens, the ſhadow of the axis will move equably in the tube; and will always fall upon *that* hour-line which is oppoſite to the ſun, at any given time.

The braſs plate *AD*, at the top, is parallel to the equator, and the axis *EFG* is perpendicular to it. If right lines be drawn from the center of this plate, to the upper ends of the equidiſtant parallel lines on the outſide of the tube; theſe right lines will be the hour-lines on the equinoctial dial *AD*, at 15 degrees diſtance from each other: and the hour-letters may be ſet to them as in the figure. Then, as the ſhadow of the axis within the tube comes on the hour-lines of the tube, it will cover the like hour-lines on the equinoctial plate *AD*.

If a thin horizontal plate *ef* be put within the tube, ſo as its edge may touch the tube all around; and right lines be drawn from the center of that plate to thoſe points of its edge which are cut by the parallel hour-lines on the tube; theſe right lines will be the hour-lines of a horizontal dial, for the latitude to which the tube is elevated. For, as the ſhadow of the axis comes ſucceſſively to the hour-lines of the tube, and covers them, it will then cover the like hour-lines on the horizontal plate *ef*, to which the hours may be ſet; as in the figure.

If

If a thin vertical plate, *g C*, be put within the tube, ſo as to front the meridian or 12 o'clock line thereof, and the edge of this plate touch the tube all around; and then, if right lines be drawn from the center of the plate to thoſe points of its edge which are cut by the parallel hour-lines on the tube; theſe right lines will be hour-lines of a vertical ſouth dial: and the ſhadow of the axis will cover them at the ſame times when it covers thoſe of the tube.

If a thin plate be put within the tube ſo, as to decline, or incline, or recline, by any given number of degrees; and right lines be drawn from its center to the hour-lines of the tube; theſe right lines will be the hour-lines of a declining, inclining, or reclining dial, anſwering to the like number of degrees, for the latitude to which the tube is elevated.

And thus, by this ſimple machine, all the principles of dialling are made very plain, and evident to the ſight. And the axis of the tube (which is parallel to the axis of the world in every latitude to which it is elevated) is the ſtile or gnomon for all the different kinds of ſun-dials.

And laſtly, if the axis of the tube be drawn out, with the plates *AD*, *ef*, and *g C* upon it; and ſet up in ſun-ſhine, in the ſame poſition as they were in the tube; you will have an equinoctial dial *AD*, a horizontal dial *ef*, and a vertical ſouth dial *g C*; on all which, the time of the day will be ſhewn by the ſhadow of the axis or gnomon *E F G*.

Let us now ſuppoſe that, inſtead of a glaſs tube, *A B C D* is a cylinder of wood; on which the 24 parallel hour lines are drawn all around, at equal diſtances from each other; and that, from the points at top, where theſe lines end, right lines are drawn toward the center, on the flat ſurface *A D*: Theſe right lines will be the hour-lines on an equinoctial dial, for the latitude of the place to

 which

which the cylinder is elevated above the horizontal foot or pedestal *H*; and they are equidistant from each other, as in *Fig.* 2. which is a full view of the flat surface or top *AD* of the cylinder, seen obliquely in *Fig.* 1. And the axis of the cylinder (which is a straight wire *EFG* all down its middle) is the stile or gnomon; which is perpendicular to the plane of the equinoctial dial, as the earth's axis is perpendicular to the plane of the equator.

To make a horizontal dial, by the cylinder, for any latitude to which its axis is elevated; draw out the axis and cut the cylinder quite through, as at *ehfg*, parallel to the horizontal board *H*, and take off the top part *eADfe*; and the section *ehfge* will be of an elliptical form, as in *Fig.* 3. Then, from the points of this section (on the remaining part *eBCf*) where the parallel lines on the outside of the cylinder meet it, draw right lines to the center of the section; and they will be the true hour lines for a horizontal dial, as *abcda* in *Fig.* 3. which may be included in a circle drawn on that section. Then put the wire into its place again, and it will be a stile for casting a shadow on the time of the day, on that dial. So, E (Fig. 3.) is the stile of the horizontal dial, parallel to the axis of the cylinder.

To make a vertical south dial by the cylinder, draw out the axis, and cut the cylinder perpendicularly to the horizontal board *H*, as at *giCkg*, beginning at the hour line (*BgeA*) of XII. and making the section at right angles to the line *SHN* on the horizontal board. Then, take off the upper part *gADC*, and the face of the section thereon will be elliptical, as shewn in *Fig.* 4. From the points in the edge of this section, where the parallel hour lines on the round surface of the cylinder meet it, draw right lines to the center of the section; and they will be the true hour lines on a vertical direct south dial, for the latitude to which the cylinder was elevated: and will appear as in *Fig.* 4. on which the vertical dial may be made of a circular shape, or of a square shape as represented in the figure. And *F* will be its stile parallel to the axis of the cylinder.

And thus, but cutting the cylinder any way, so as its section may either incline, or decline, or recline, by any given number of degrees; and from those points in the edge of the section where the outside parallel hour lines meet it, draw right lines to the center of the section; and they will be the true hour lines, for the like declining, reclining, or inclining dial: And the axis of the cylinder will always be the gnomon or stile of the dial. For, whichever way the plane of the dial lies, its stile (or the edge thereof that casts the shadow on the hours of the day) must be parallel to the earth's axis, and point toward the elevated pole of the heavens.

To delineate a Sun-Dial on Paper; which, when pasted round a Cylinder of Wood, shall shew the Time of the Day, the Sun's Place in the Ecliptic and his Altitude, at any Time of Observation. See PLATE IX.

Draw the right line *a A B*, parallel to the top of the paper; and, with any convenient opening of the compasses, set one foot in the end of the line at *a*, as a center, and with the other foot describe the quadrantal arc *A E*, and divide into 90 equal parts or degrees. Draw the right line *A C*, at right angles to *a A B*, and touching the quadrant *A E* at the point *A*. Then, from the center *a*, draw right lines through as many degrees of the quadrant, as are equal to the sun's altitude at noon, on the longest day of the year, at the place for which the dial is to serve; which altitude, at London, is 62 degrees: and continue these right lines till they meet the tangent line *A C*; and, from these points of meeting, draw straight lines across the paper, parallel to the first right line *A B*, and they will be the parallels of the sun's altitude, in whole degrees, from sun-rise till sun-set, on all the days of the year.——These parallels of altitude must be drawn out to the right line *B D*, which must be parallel to *A C*, and as far from it as is equal to the intended circumference of the cylinder on which the paper is to be pasted, when the dial is drawn upon it.

Divide

Divide the ſpace between the right lines *AC* and *BD* (at top and bottom) into twelve equal parts, for the twelve ſigns of the ecliptic; and, from mark to mark, of theſe diviſions at top and bottom, draw right lines parallel to *AC* and *BD*; and place the characters of the 12 ſigns in theſe twelve ſpaces, at the bottom, as in the figure; beginning with ♑ or Capricorn, and ending with ♓ or Piſces. The ſpaces including the ſigns ſhould be divided by parallel lines into halves; and, if the breadth will admit of it without confuſion, into quarters alſo.

At the top of the dial, make a ſcale of the months and days of the year, ſo as the days may ſtand over the ſun's place for each of them in the ſigns of the ecliptic. The ſun's place, for every day of the year, may be found by any common ephemeris: and here it will be beſt to make uſe of an ephemeris for the ſecond year after leap year; as the neareſt mean for the ſun's place on the days of the leap year, and on theſe thoſe of the firſt, ſecond, and third year after.

Compute the ſun's altitude for every hour (in the latitude of your place) when he is in the beginning, middle, and end of each ſign of the ecliptic; his altitude at the end of each ſign being the ſame as at the beginning of the next. And, in the upright parallel lines, at the beginning and middle of each ſign, make marks for theſe computed altitudes among the horizontal parallels of altitude, reckoning them downward, according to the order of the numeral figures ſet to them at the right hand, anſwering to the like diviſions of the quadrant at the left. And, through theſe marks, draw the curve hour-lines, and ſet the hours to them, as in the figure, reckoning the forenoon hours downward, and the afternoon hours upward.——The ſun's altitude ſhould alſo be computed for the half hours; and the quarter lines may be drawn, very nearly in their proper places, by eſtimation and accuracy of the eye. Then, cut off the paper at the left hand, on which the quadrant was drawn, cloſe by the right line *AC*, and all the paper at the right hand cloſe by the right line

line *BD*; and cut it alſo cloſe by the top and bottom horizontal lines; and it will be fit for paſting round the cylinder.

This cylinder is repreſented in miniature by *Fig* 1. of PLATE X. It ſhould be hollow, to hold the ſtile *DE* when it is not uſed. The crooked end of the ſtile is put into a hole in the top *AD* of the cylinder; and the top goes on tightiſh, but muſt be made to turn round on the cylinder, like the lid of a paper ſnuff-box. The ſtile muſt ſtand ſtraight out, perpendicular to the ſide of the cylinder, juſt over the right line *AB* in PLATE IX, where the parallels of the ſun's altitude begin: and the length of the ſtile, or diſtance of its point *e* from the cylinder, muſt be equal to the radius *a A* of the quadrant *AE* in PLATE IX.

The method of uſing this dial is as follows.

Place the horizontal foot *BC* of the cylinder on a level table where the ſun ſhines, and turn the top *AD* till the ſtile ſtands juſt over the day of the then preſent month. Then turn the cylinder about, on the table, till the ſhadow of the ſtile falls upon it, parallel to theſe upright lines which divide the ſigns; that is, till the ſhadow be parallel to a ſuppoſed axis in the middle of the cylinder: and then, the point, or loweſt end of the ſhadow, will fall upon the time of the day, as it is before or after noon, among the curve hour-lines; and will ſhew the ſun's altitude at that time, among the croſs parallels of his altitude, which go round the cylinder: and, at the ſame time, it will ſhew in what ſign of the ecliptic the ſun then is, and you may very nearly gueſs at the degree of the ſign, by eſtimation of the eye.

The ninth plate, on which this dial is drawn, may be cut out of the book, and paſted round a cylinder whoſe length is 6 inches and 6 tenths of an inch, below the moveable top; and its diameter 2 inches and 24 hundred parts of an inch. —— Or, I ſuppoſe the

copper-plate prints of it may be had at Mr. *Cadell's*, bookseller in the Strand, London. But it will only do for London, and other places of the same latitude.

When a level table cannot be had, the dial may be hung by the ring *F* at the top. And when it is not used, the wire that serves for a stile may be drawn out, and put up within the cylinder; and the machine carried in the pocket.

To make three Sun-Dials upon three different Planes, so as they may all shew the Time of the Day by one Gnomon.

On the flat board *A B C*, describe a horizontal dial, according to any of the rules laid down in the Lecture on Dialling; and give it its gnomon *F G H*, the edge of the shadow from the side *F G* being that which shews the time of the day.

To this horizontal or flat board, join the upright board *E D C*, touching the edge *G H* of the gnomon. Then, making the top of the gnomon at *H* the center of the vertical south dial, describe a south dial on the board *E D C*.

Lastly, on a circular plate *I K* describe an equinoctial dial, all the hours of which dial are equidistant from each other: and making a slit *c d* in that dial, from its edge to its center, in the XII o'clock line; put the said dial on the gnomon *F G*, as far as the slit will admit of; and the triple dial will be finished; the same gnomon serving all the three, and shewing the same time of the day on each of them.

An universal Dial on a plain Cross.

This dial is represented by *Fig.* 1. of PLATE XI, and is moveable on a joint *C*, for elevating it to any given latitude, on the quadrant

quadrant *C o 9 0*, as it stands upon the horizontal board *A*. The arms of the cross stands at right angles to the middle part; and the top of it, from *a* to *n*, is of equal length with either of the arms *ne* or *mk*.

Having set the middle line *t u* to the latitude of your place, on the quadrant, the board *A* level, and the point *N* northward by the needle; the plane of the cross will be parallel to the plane of the equator; and the machine will be rectified.

Then, from III o'clock in the morning, till VI; the upper edge *k l* of the arm *i o* will cast a shadow on the time of the day on the side of the arm *c m*: from VI till IX, the lower edge *i* of the arm *i o* will cast a shadow on the hours on the side *o q*. From IX in the morning to XII at noon, the edge *a b* of the top part *a n* will cast a shadow on the hours on the arm *n e f*: from XII to III in the afternoon, the edge *c d* of the top part will cast a shadow on the hours on the arm *k l m*: from III to VI in the evening; the edge *g h* will cast a shadow on the hours on the part *p q*; and from VI till IX, the shadow of the edge *e f* will shew the time on the top part *an*.

The breadth of each part, *ab*, *ef*, &c. must be so great, as never to let the shadow fall quite without the part or arm on which the hours are marked, when the sun is at his greatest declination from the equator.

To determine the breadth of the sides of the arms which contain the hours, so as to be in just proportion to their length; make an angle *A B C* (Fig. 2.) of $23\frac{1}{2}$ degrees, which is equal to the sun's greatest declination: and suppose the length of each arm, from the side of the long middle part, and also the length of the top-part above the arms, to be equal to *B d*.

E Then,

Then, as the edges of the shadow, from each of the arms, will be parallel to Be, making an angle of $23\frac{1}{2}$ degrees with the side Bd of the arm when the sun's declination is $23\frac{1}{2}$ degrees; 'tis plain, that if the length of the arm be Bd, the least breadth that it can have, to keep the edge Be of the shadow $Begd$ from going off the side of the arm de before it comes to the end ed thereof, must be equal to ed or dB. But, in order to keep the shadow within the quarter divisions of the hours, when it comes near the end of the arm, the breadth thereof should be still greater, so as to be almost doubled, on account of the distance between the tips of the arms.

To place the hours right on the arms, take the following method.

Lay down the cross $acbd$ (*Fig.* 3.) on a sheet of paper; and, with a black lead pencil, held close to it, draw its shape and size on the paper. Then taking the length ae in your compasses, and setting one foot in the corner *A*, with the other foot describe the quadrantal arc ef.—— Divide this arc into six equal parts, and through the division-marks draw right lines ag, ab, &c. continuing three of them to the arm ce, which are all that can fall upon it; and they will meet the arm in these points through which the lines that divide the hours from each other (as in *Fig.* 1.) are to be drawn right across it.

Divide each arm, for the three hours it contains, in the same manner; and set the hours to their proper places (on the sides of the arms) as they are marked in Fig. 3. Each of the hour spaces should be divided into four equal parts, for the half hours and quarters, in the quadrant ef; and right lines should be drawn through these division-marks in the quadrant, to the arms of the cross; in order to determine the places thereon where the sub-divisions of the hours must be marked.

This

This is a very simple kind of universal dial; it is very easily made, and will have a pretty uncommon appearance in a garden. —— I have seen a dial of this sort, but never saw one of the kind that follows.

An universal Dial, shewing the Hours of the Day by a terrestrial Globe, and by the Shadows of several Gnomons, at the same Time: together with all the Places of the Earth which are then enlightened by the Sun; and those to which the Sun is then rising, or on the Meridian, or Setting.

This dial (*See* PLATE XII.) is made of a thick square piece of wood, or hollow metal. The sides are cut into semicircular hollows, in which the hours are placed; the stile of each hollow coming out from the bottom thereof, as far as the ends of the hollows project. The corners are cut out into angles, in the insides of which, the hours are also marked; and the edge of the end of each side of the angle serves as a stile for casting a shadow on the hours marked on the other side.

In the middle of the uppermost side, or plane, there is an equinoctial dial; in the center whereof, an upright wire is fixt, for casting a shadow on the hours of that dial, and supporting a small terrestrial globe on its top.

The whole dial stands on a pillar, in the middle of a round horizontal board, in which there is a compass and magnetic needle, for placing the *meridian* stile toward the south. The pillar has a joint with a quadrant upon it, divided into 90 degrees (supposed to be hid from sight under the dial in the figure) for setting it to the latitude of any given place; the same way as already described in the dial on the cross.

The equator of the globe is divided into 24 equal parts, and the hours are laid down upon it at these parts. The time of the day may be known by these hours, when the sun shines upon the globe.

To rectify and use this dial, set it on a level table, or sole of a window, where the sun shines, placing the meridian stile due south, by means of the needle; which will be, when the needle points as far from the north fleur-de-lis toward the west, as it declines westward, at your place. Then bend the pillar in the joint, till the black line on the pillar comes to the latitude of your place in the quadrant.

The machine being thus rectified, the plane of its dial-part will be parallel to the equator, the wire or axis that supports the globe will be parallel to the earth's axis, and the north pole of the globe will point toward the north pole of the heavens.

The same hour will then be shewn in several of the hollows, by the ends of the shadows of their respective stiles: The axis of the globe will cast a shadow on the same hour of the day, in the equinoctial dial, in the center of which it is placed, from the 20th of March to the 23d of September; and, if the meridian of your place on the globe be set even with the meridian stile, all the parts of the globe that the sun shines upon, will answer to those places of the real earth which are then enlightened by the sun. The places where the shade is just coming upon the globe, answer to all those places of the earth to which the sun is then setting; as the places where it is going off, and the light coming on, answer to all the places of the earth where the sun is then rising. And lastly, if the hour of VI be marked on the equator in the meridian of your place (as it is marked on the meridian of London in the figure) the division of the light and shade on the globe will shew the time of the day.

The

The northern stile of the dial (opposite to the southern or meridian one) is hid from sight in the figure, by the axis of the globe. The hours in the hollow to which that stile belongs, are also supposed to be hid by the oblique view of the figure: but they are the same as the hours in the front-hollow. Those also in the right and left hand semicircular hollows are mostly hid from sight; and so also are all those on the sides next the eye of the four acute angles.

The construction of this dial is as follows. *See* PLATE XIII.

On a thick square piece of wood, or metal, draw the lines *ac* and *bd*, as far from each other as you intend for the thickness of the stile *abcd*; and in the same manner, draw the like thickness of the other three stiles, *efgh*, *iklm*, and *nopq*, all standing outright as from the center.

With any convenient opening of the compasses, as *aA* (so as to leave proper strength of stuff when *KI* is equal to *aA*) set one foot in *a*, as a center, and with the other foot describe the quadrantal arc *Ac*. Then without altering the compasses, set one foot in *b* as a center, and with the other foot describe the quadrant *dB*. All the other quadrants in the figure must be described in the same manner, and with the same opening of the compasses, on their centers *e*, *f*; *i*, *k*; and *n*, *o*: and each quadrant divided into 6 equal parts, for so many hours, as in the figure; each of which parts must be subdivided into 4, for the half hours and quarters.

At equal distances from each corner, draw the right lines *Ip* and *Kp*, *Lq* and *Mq*, *Nr* and *Or*, *Ps* and *Qs*; to form the four angular hollows *IpK*, *LqM*, *NrO*, and *PsQ*; making the distances between the tips of these hollows, as *IK*, *LM*, *NO*, and *PQ*, each equal to the radius of the quadrants; and leaving sufficient room within the angular points, *p*, *q*, *r*, and *s*, for the equinoctial dial in the middle.

 To

To divide the insides of these angles properly, for the hour-spaces thereon; take the following method.

Set one foot of the compasses in the point *I*, as a center; and open the other to *K*, and with that opening, describe the arc *Kt*: then, without altering the compasses, set one foot in *K*, and with the other foot describe the arc *It*. Divide each of these arcs, from *I* and *K* to their intersection at *t*, into four equal parts; and from their centers *I* and *K*, through the points of division, draw the right lines *I* 3, *I* 4, *I* 5, *I* 6, *I* 7; and *K* 2, *K* 1, *K* 12, *K* 11; and they will meet the sides *Kp* and *Ip* of the angle *IpK* where the hours thereon must be placed. And these hour-spaces in the arcs must be subdivided into four equal parts, for the half hours and quarters.—Do the like for the other three angles, and draw the dotted lines, and set the hours in the insides where those lines meet them, as in the Figure: and the like hour-lines will be parallel to each other in all the quadrants and in all the angles.

Mark points for all these hours, on the upper side; and cut out all the angular hollows, and the quadrantal ones quite through the places where their four gnomons must stand; and lay down the hours on their insides, as in Plate XII, and then set in their four gnomons, which must be as broad as the dial is thick; and this breadth and thickness must be large enough to keep the shadows of the gnomons from ever falling quite out at the sides of the hollows, even when the sun's declination is at the greatest.

Lastly, draw the equinoctial dial in the middle, all the hours of which are equidistant from each other: and the dial will be finished.

As the sun goes round, the broad end of the shadow of the stile *acbd* will shew the hours in the quadrant *Ac*, from sun-rise till VI in the morning; the shadow from the end *M* will shew the hours on the side *Lq* from V to IX in the morning; the shadow of the stile *efgh* in the quadrant *Dg* (in the long days) will show the hours from

from ſun-riſe till VI in the morning; and the ſhadow of the end *N* will ſhew the morning hours, on the ſide *O r*, from III to VII.

Juſt as the ſhadow of the northern ſtile *a b c d* goes off the quadrant *A c*, the ſhadow of the ſouthern ſtile *i k l m* begins to fall within the quadrant *F l*, at VI in the morning; and ſhews the time, in that quadrant, from VI till XII at noon; and from noon till VI in the evening in the quadrant *m E*. And the ſhadow of the end *O*, ſhews the time from XI in the forenoon till III in the afternoon, on the ſide *r N*; as the ſhadow of the end *P* ſhews the time from IX in the morning till I o'clock in the afternoon, on the ſide *Q s*.

At noon, when the ſhadow of the eaſtern ſtile *e f g h* goes off the quadrant *b C* (in which it ſhewed the time from VI in the morning till noon, as it did in the quadrant *g D* from ſun-riſe till VI in the morning) the ſhadow of the weſtern ſtile *n o p q* begins to enter the quadrant *H p*; and ſhews the hours thereon from XII at noon till VI in the evening; and after *that* till ſun-ſet, in the quadrant *q G*: and the end *Q* caſts a ſhadow on the ſide *P s* from V in the evening till IX at night, if the ſun be not ſet before that time.

The ſhadow of the end *I* ſhews the time on the ſide *K p* from III till VII in the afternoon; and the ſhadow of the ſtile *a b c d* ſhews the time from VI in the evening till the ſun ſets.

The ſhadow of the upright central wire, that ſupports the globe at top, ſhews the time of the day, in the middle or equinoctial dial, all the ſummer half year, when the ſun is on the north ſide of the equator.

In this ſupplement to my book of Lectures, all the machines that I have added to my apparatus, ſince that book was printed, are deſcribed, excepting two; one of which is a model of a mill for ſawing timber, and the other is a model of the great engine at London-bridge,

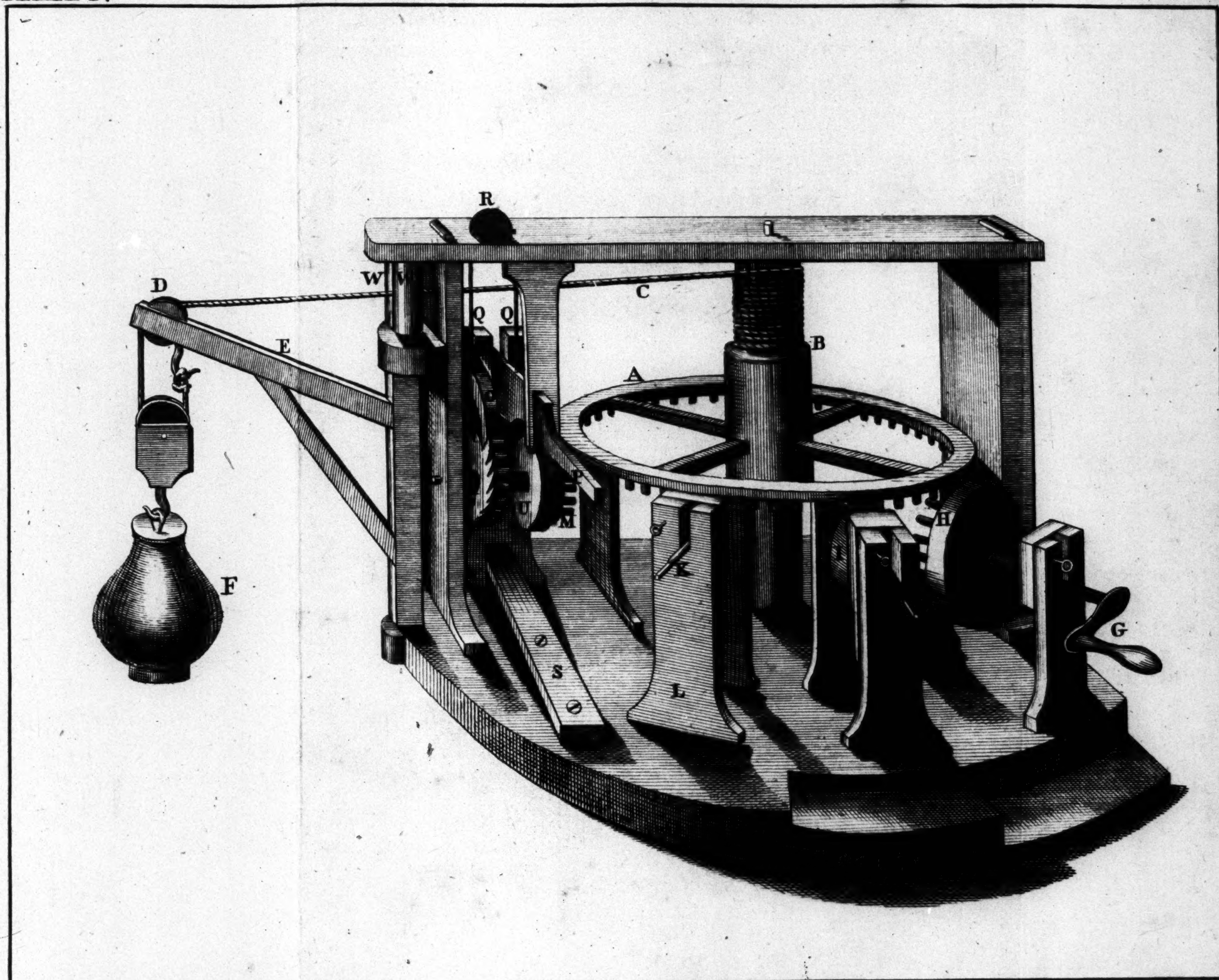
for raising water. And my reasons for leaving them out are as follow.

First, I found it impossible to make such a drawing of the saw-mill as could be understood; because, in whatever view it be taken, a great many parts of it hide others from sight. And, in order to shew it in my Lectures, I am obliged to turn it into all manner of positions.

Secondly, because any person who looks on *Fig.* 1. of PLATE XII in the book, and reads the account of it in the fifth lecture therein, will be able to form a very good idea of the London-bridge-engine, which has only two wheels and two trundles more than there are in Mr. *Aldersea*'s engine, from which the said figure was taken.

FINIS.

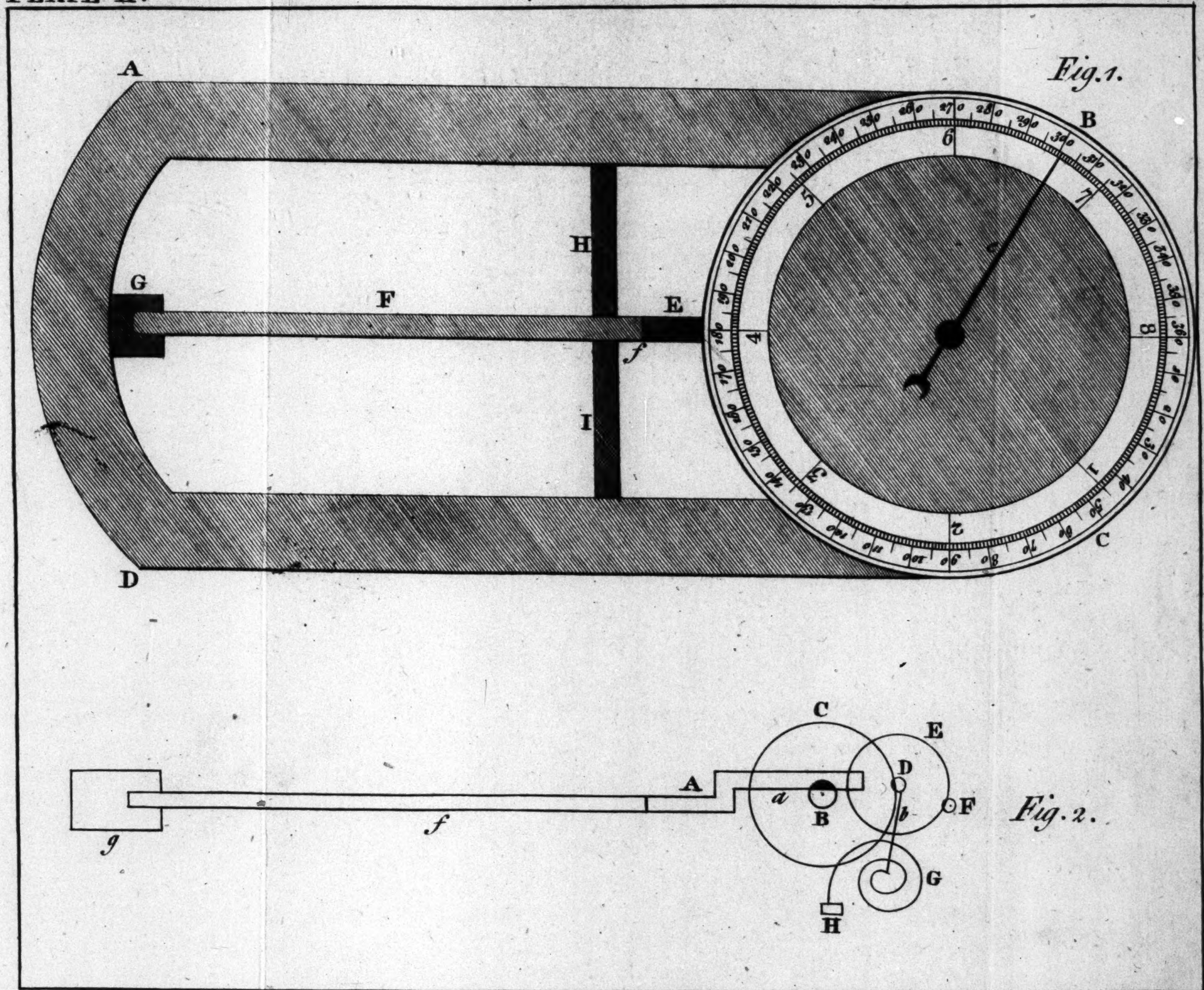
PLATE I.



T. Ferguson delin.

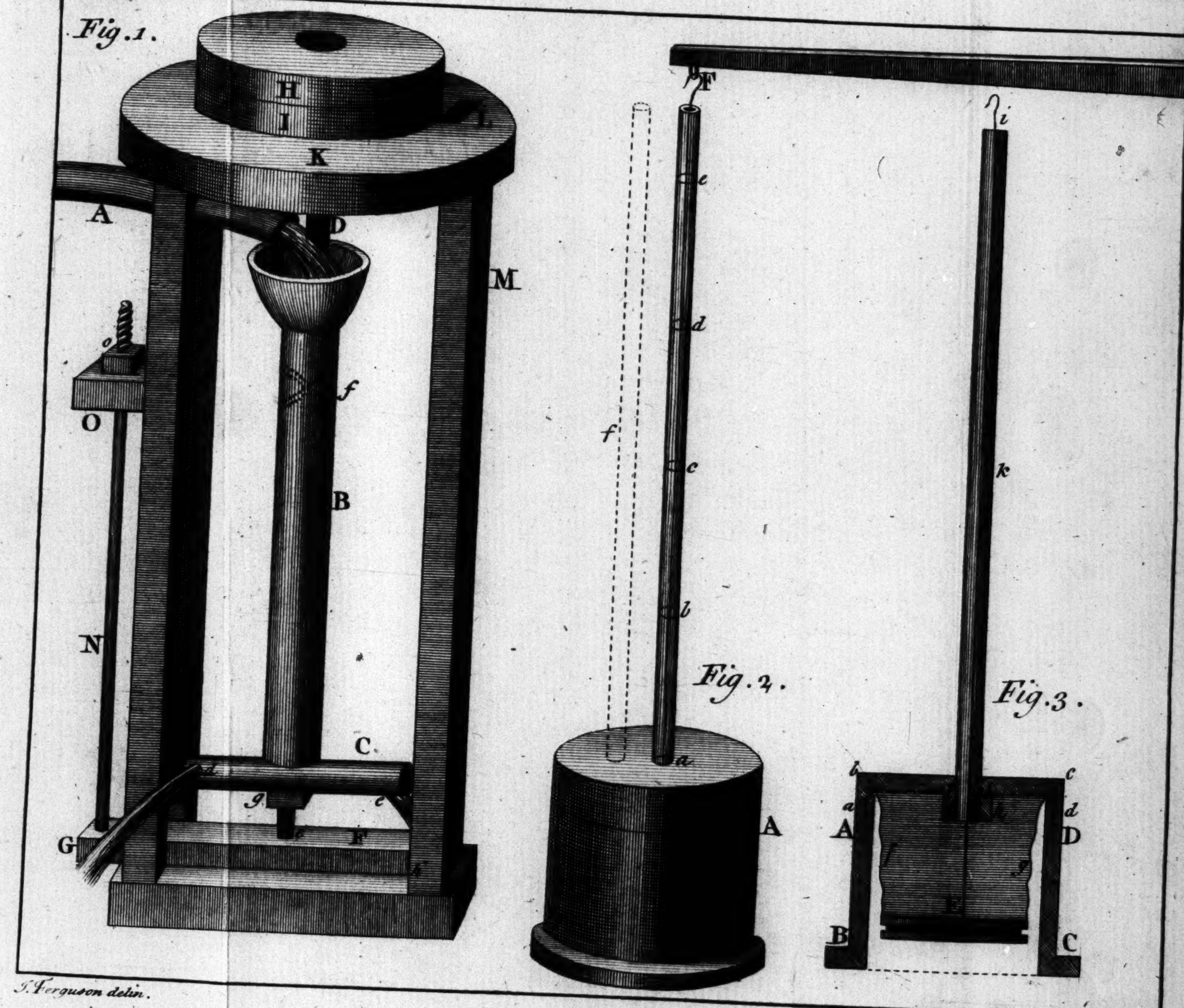
J. Mynde sc.

PLATE II.



J. Ferguson delin. J. Mynde sc.

PLATE III.



J. Ferguson delin.

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PLATE IV.

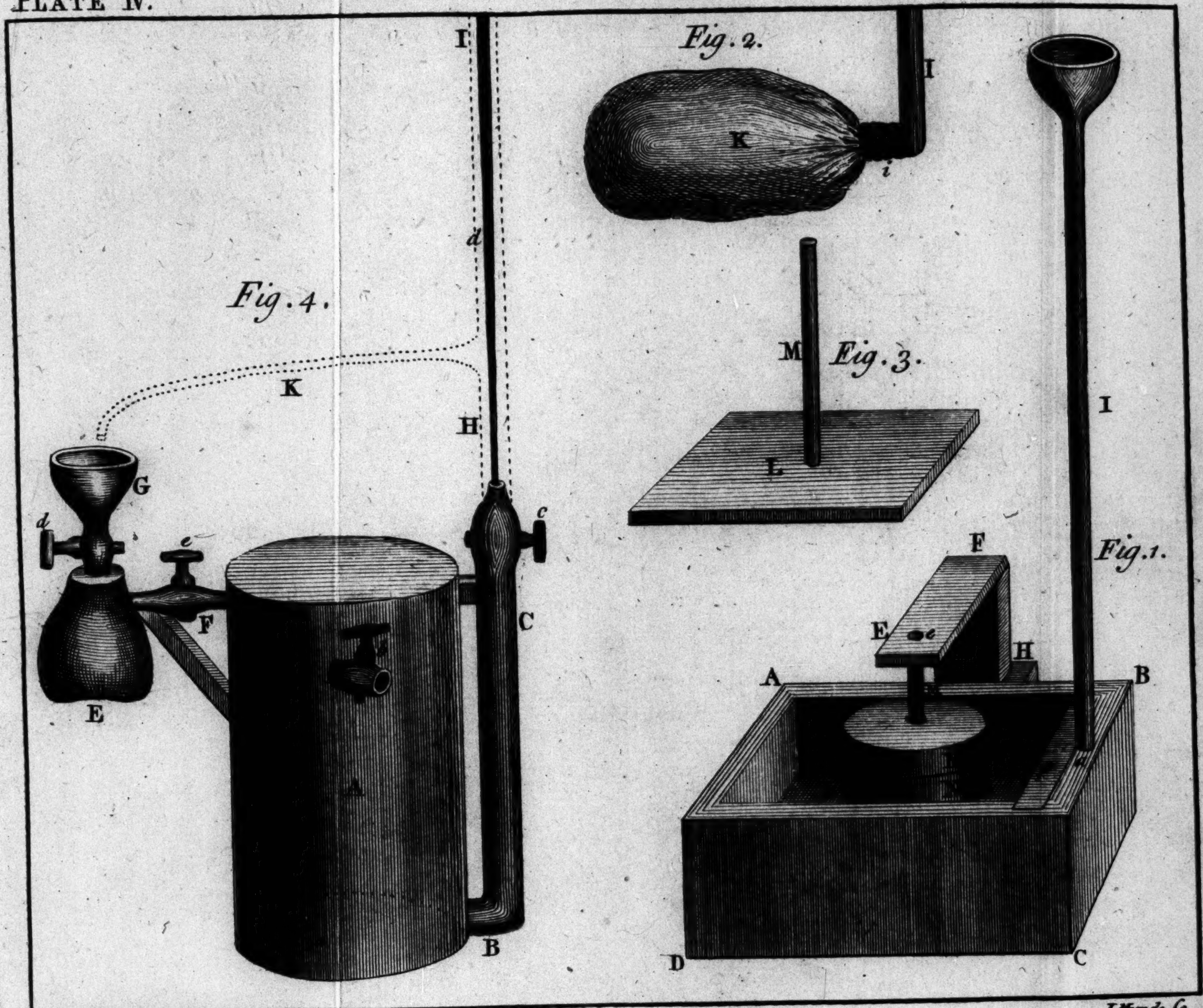

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PLATE V.

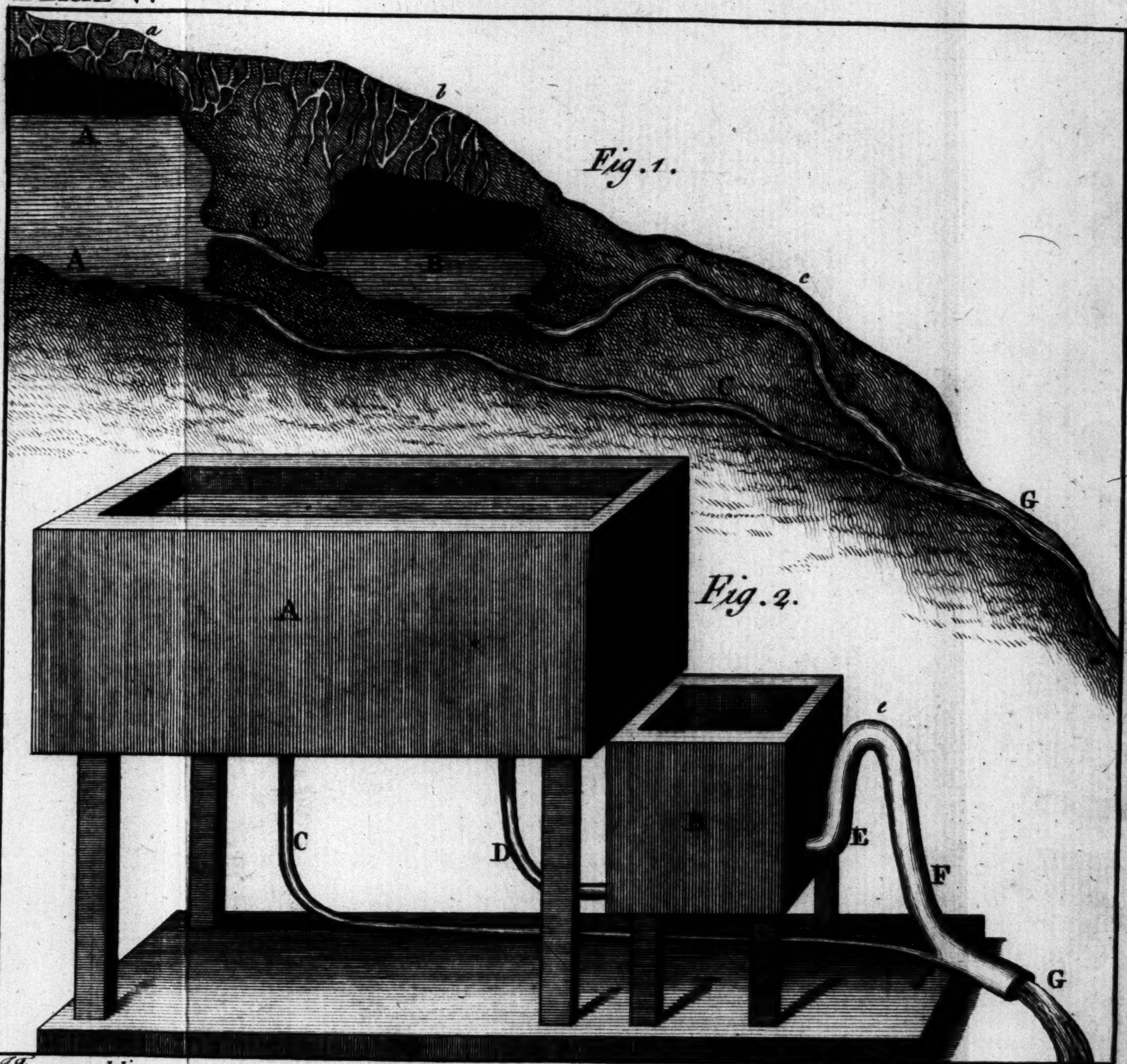

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PLATE VI.

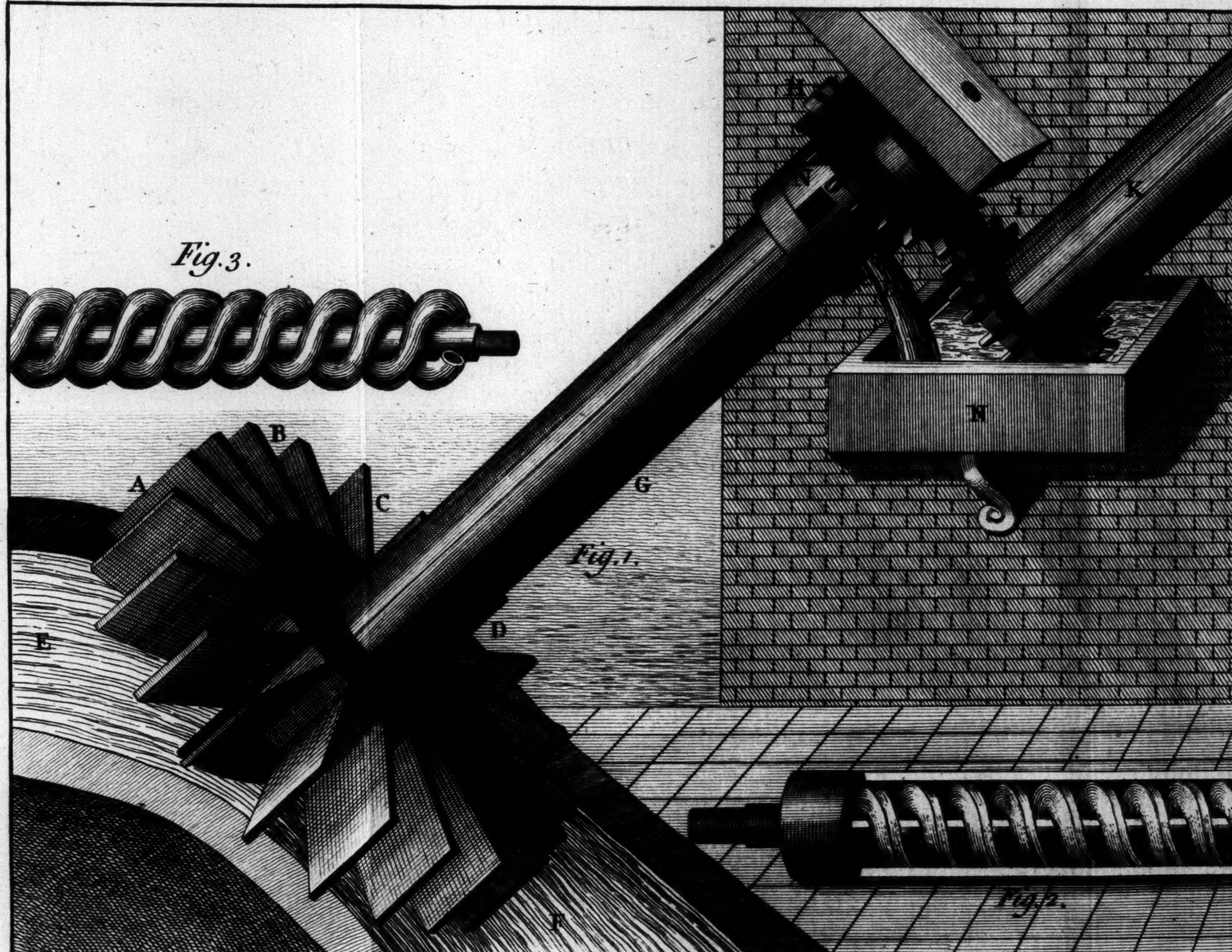

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PLATE VII.

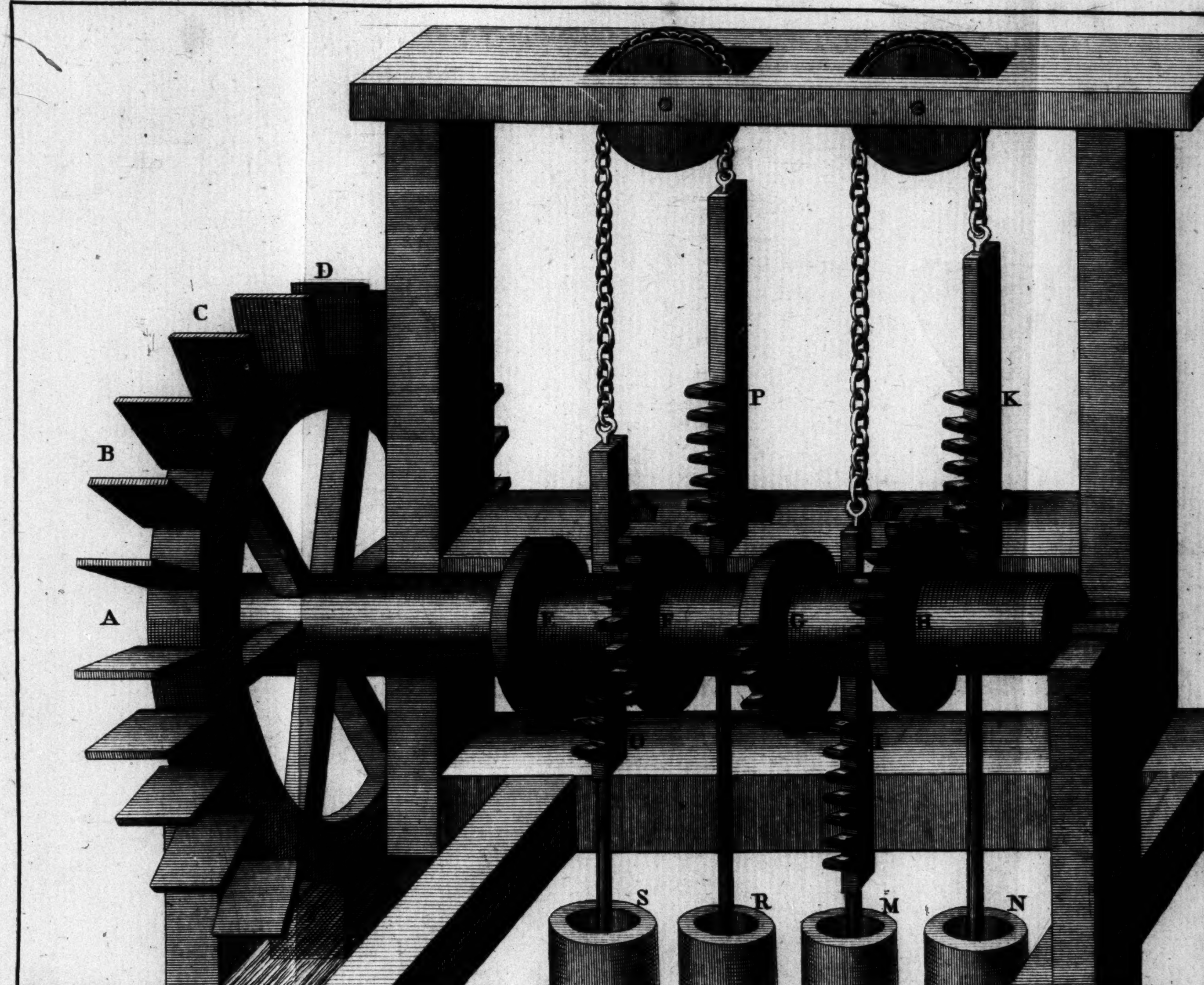

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PLATE VIII.

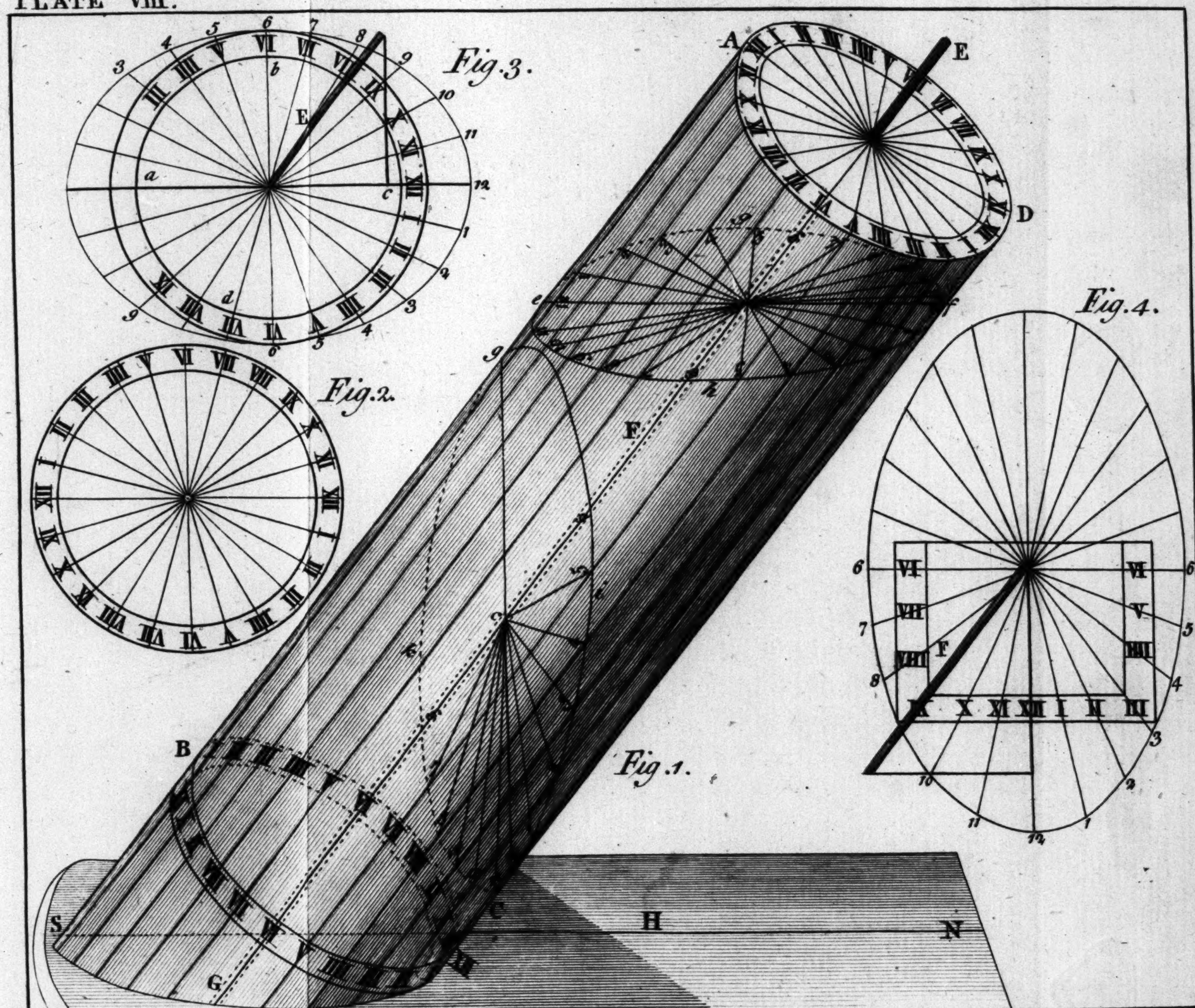

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PLATE IX.

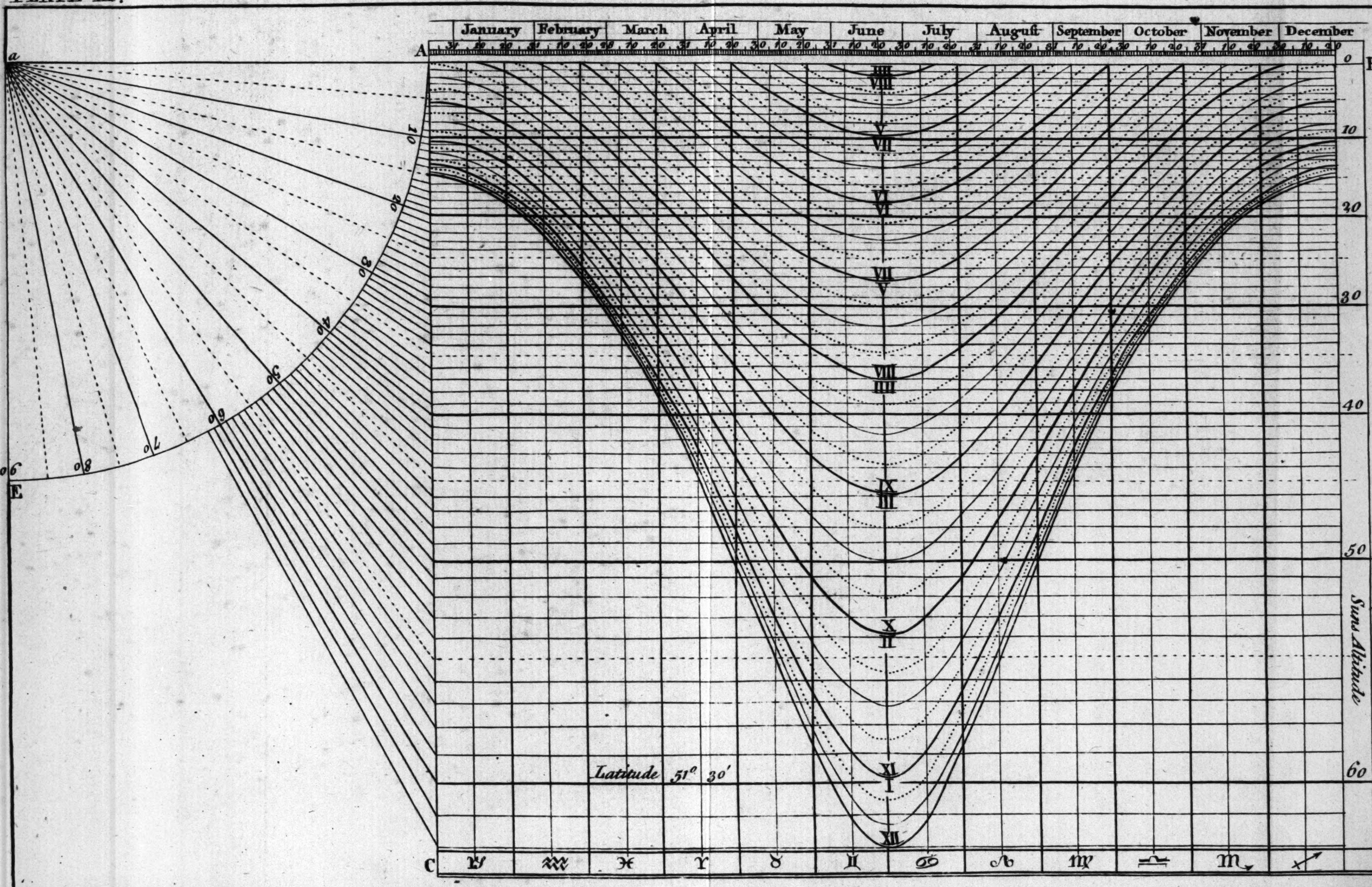

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PLATE X.

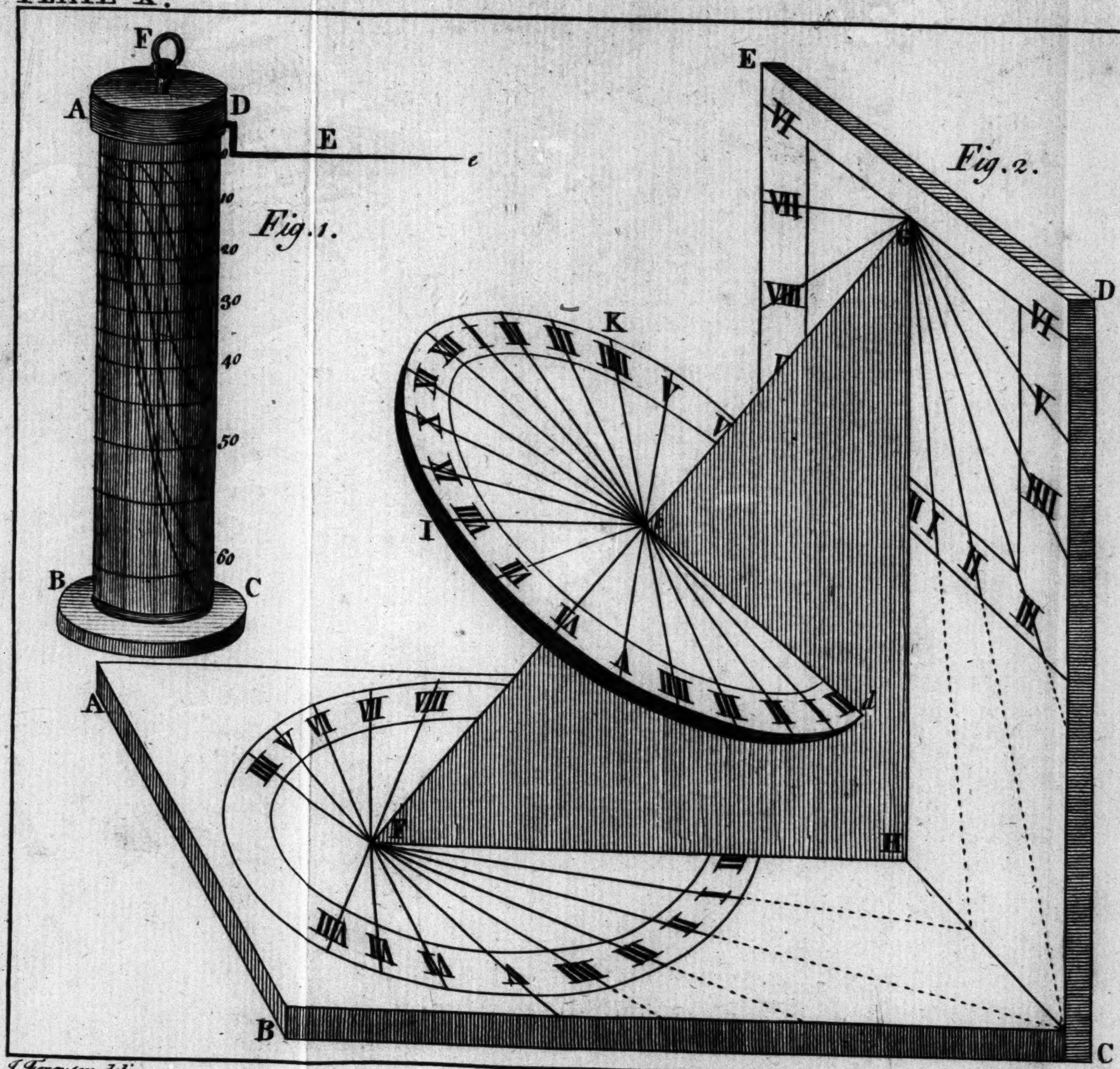

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PLATE XI.

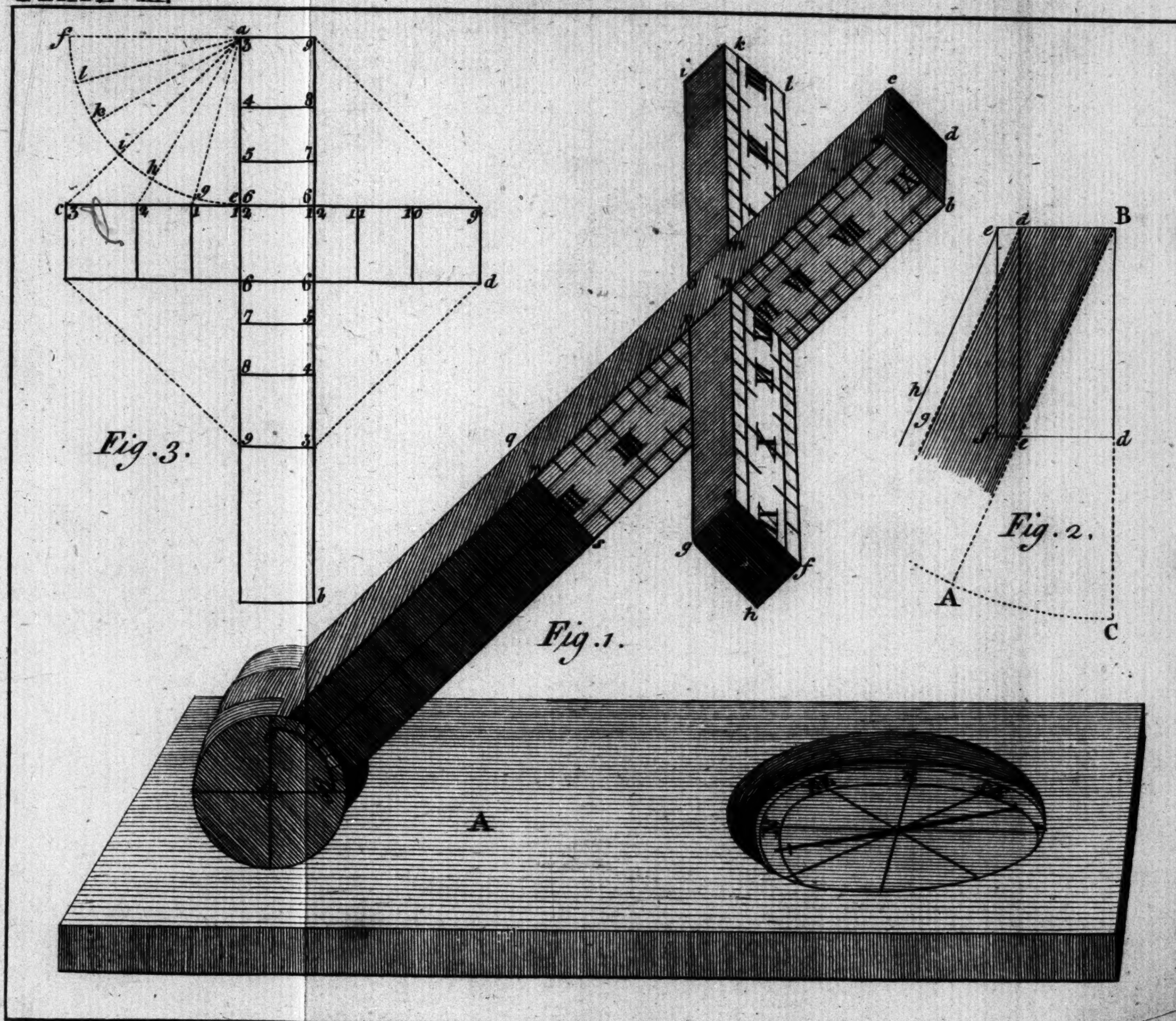

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PLATE XII.

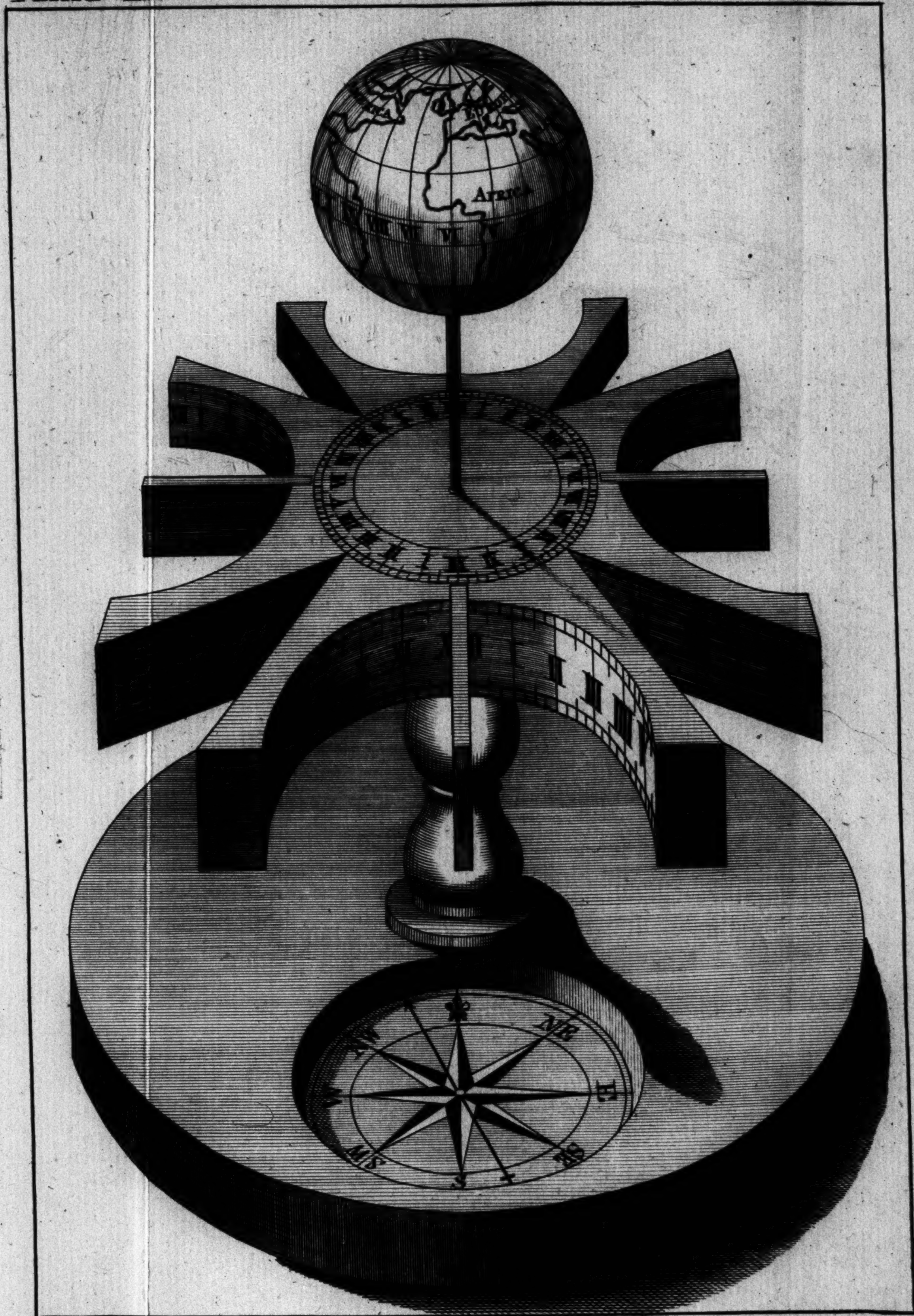

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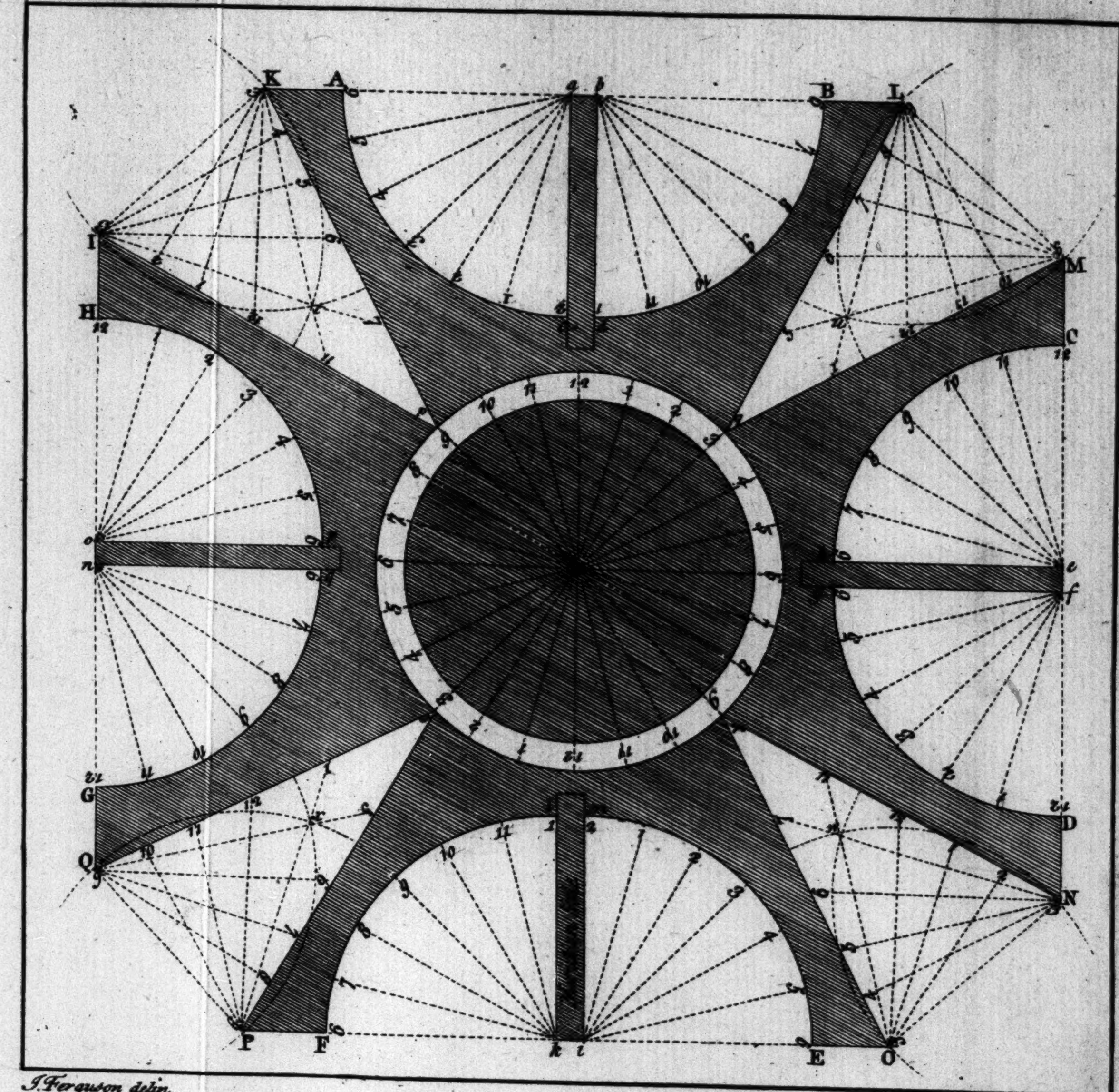
PLATE XIII.



J. Ferguson delin.

J. Wynde sc.